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OF THE
ROYAL AERONAUTICAL SOCIETY

(FOUNDED 1897 in succession to the ANNUAL REPORTS)

Edited for the Council by J. LAURENCE PRITCHARD, Fellow

No. 184. APRIL, 1926. Vol. XXX.

NOTICES

Elections

The following members were elected at a Council Meeting held on March 16th :—

Honorary Fellow.—Mr. F. W. Lanchester.

Associate Fellows.—Mr. J. F. Craig, Mr. N. Davey and Mr. H. O. Sommer.

Associates.—Mr. F. W. Atkinson, Mr. R. Bance, Capt. A. Gordon Bond, Mr. E. E. H. Evans, Mr. F. Hoult, Mr. W. G. Kimber, Mr. C. A. Mann, Mr. W. Moss, Mr. A. D. Patwardham, F./O. R. L. Ragg, Mr. J. Reid and Mr. C. J. Wood.

Gold Medal

The Council have awarded the Gold Medal of the Society to Mr. F. W. Lanchester in recognition of the valuable services he has rendered to the science of aeronautics. The medal will be presented to him on the occasion of the Wilbur Wright Lecture, which he has consented to deliver on May 27th.

Informal Discussion

The attention of members is particularly drawn to an Informal Discussion which will be held on Wednesday, April 14th next, in the Library, 7, Albemarle Street, W.1, at 6 p.m. The discussion will be on "The Relative Merits of Water-Cooled and Air-Cooled Engines." The case for the water-cooled engine will be stated by Captain G. S. Wilkinson, and that for the air-cooled by Mr. J. D. Siddeley. No tickets will be needed for admission.

Coventry Branch

The first lecture before the Coventry Branch was delivered by Mr. W. S. Farren, a Fellow of the Society, on the Autogiro, Major F. M. Green being in the chair. There was an excellent attendance and a very interesting discussion. The branch is to be congratulated upon the rapid progress it is making in stimulating interest in aviation in Coventry and the neighbouring district.

Students' Prize

Lieutenant R. de Aboim, Brazilian Navy, an Associate Fellow of the Society, has generously offered to present a prize of five guineas for a Students' Paper. The conditions of the award will be announced in a forthcoming issue of the Journal.

Library Fund

In addition to the donations acknowledged last month, the following have been made to the Library Fund:—Mr. C. H. Gray, £1 1s. od.; Wing Comdr.

H. R. Busteed, 14/-; Air Commodore F. V. Holt, £1 1s. od.; Mr. T. C. Sharwood, 14/-; Mr. C. T. Travers, 14/-; Mr. W. W. Hackett, £1 1s. od.; Mr. T. W. Willis, £1 1s. od.; Mr. H. B. Gledhill, 14/-; Lieut.-Colonel V. C. Richmond, 14/-; Professor O. S. Sinnatt, 14/-; Mr. G. G. Parnall, £2 2s. od.; Brig.-Gen. W. H. Caddell, £1 1s. od.; Mr. A. Gouge, 14/-.

Presentations to the Library

The Council desire to acknowledge gratefully the gift of a copy of "Metallurgy and its Influence on Modern Progress," presented by Sir Robert Hadfield, Bart., Fellow; a copy of "The Adventure of Wrangel Island," by Mr. Griffith Brewer, Fellow; and a copy of "Aircraft Steels and Materials," presented by Mr. R. Tarleton.

Mr. Brewer has very kindly had prepared a typewritten copy and also a photostat copy of Knight's diary, which forms the basis of Mr. Stefansson's book, "The Adventure of Wrangel Island." The photostat copy will enable any doubts to be cleared up in cases where there is any doubt as to the actual wording either in the book or the typewritten copy. This photostat is the only one in any British library, and so forms a unique record of a great achievement.

Lantern Slides

The Council desire to acknowledge gratefully the gift of slides of racing machines from Mr. H. J. Penrose. The Council also record their thanks to Mr. W. S. Farren for lending his slides of the de la Cierva Autogiro to the Loan Collection for the use of members; and to the Westland Aircraft Works, of Yeovil, for slides of the Widgeon, Wood Pigeon and Westland Yeovil Bomber.

Library

The following publications from the Air Ministry have been placed in the Library:—Jupiter Series IV. Aero Engine and H. P. Jaguar III. Aero Engine; Regulations Governing the Graduation of Altimeters; Apparatus, Supplies Dropping, Marks I. and II.; and Method of Starting Engines of Light Aeroplanes. The following books have been received:—"An Atlas of the World's Airways," published by Messrs. F. J. Field; "Graphical Methods of Plotting from Air Photographs, 1925," by Lieut.-Col. King; a pamphlet on an "Experimental Verification of Castigliano's Principle of Least Work," by Prof. A. J. Sutton Pippard and Mr. A. J. Baker; a Smithsonian pamphlet, "The Probable Solution of the Climate Problem in Geology," by W. Ramsey; "Some Commercial Uses of Aerial Photographic Surveying," by R. A. Logan; Abhandlungen aus dem Aerodynamischen Institut, Aachen; R.A.E. Report No. B.A. 539, "Experiments on Steam Radiators," by R. G. Harris and L. E. Caygill; "Civil Aviation," an official report from the U.S.A.; "Il Volo Transpolare," by U. Nobili; "The Broken Trident," by E. F. Spanner; "Skyways," by A. J. Cobham; Report of a Meeting of the International Meteorological Organisation, April 1925; and "Aviation Medicine," by L. H. Bauer.

Students' Section Programme

Thursday, April 15th, 6.0 p.m., in the Library.—"Supercharged Aero Engines," by Mr. R. F. R. Pierce.

Saturday, April 24th.—Visit to Vickers' Works, Weybridge.

Saturday, May 8th.—Visit to the Fairey Aviation Works, Hayes.

Wilbur Wright Memorial Lecture

Mr. F. W. Lanchester will deliver the fourteenth Wilbur Wright Memorial Lecture on May 27th. The title of the lecture will be announced in due course.

The Month's Arrangements

Thursday, April 8th, 6.30 p.m.—At the Royal Society of Arts, 18, John Street, Adelphi, W.C.2. "A 35,000-Mile Flight," by the Marchese De Pinedo.

Wednesday, April 14th, 6.0 p.m.—In the Library. Informal Discussion, "The Relative Merits of Water-Cooled and Air-Cooled Engines."

Thursday, April 15th, 6.0 p.m.—In the Library. Students' Meeting. "Supercharged Aero Engines," by Mr. R. F. R. Pierce.

Thursday, April 22nd, 6.30 p.m.—At the Royal Society of Arts. "The Tailless Aeroplane," by Capt. G. T. R. Hill, M.C., A.F.R.Ae.S.

Saturday, April 24th.—Visit to Vickers' Works, Weybridge.

Thursday, April 29th, 6.30 p.m.—In the Library. "The Results of Recent Airship Flight Tests," by Lieut.-Col. V. C. Richmond, O.B.E., A.F.R.Ae.S.

J. LAURANCE PRITCHARD, *Hon. Secretary.*

ANNUAL GENERAL MEETING.

MINUTES.

The Sixty-First Annual General Meeting of members of the Society was held in the Society's Offices, 7, Albemarle Street, W., at 5.0 p.m., on Thursday, March 25th, 1926, the Vice-Chairman (Lieutenant-Colonel H. T. Tizard, A.F.C.) presiding.

Mr. Balston, Wing Commander T. R. Cave-Browne-Cave and Mr. S. H. Evans were appointed scrutineers of the ballot for the election of new members to the Council.

The Minutes of the last Annual General Meeting were taken as read and confirmed.

The Council's report for the year 1925-1926 and the balance sheet and accounts as published in the March issue of the Journal were adopted on the proposal of Mr. Griffith Brewer, seconded by Major Mayo.

The Council's proposal to add the following rule:—

> "A Postal Vote may be ordered by the Council on any question affecting the welfare of the Society"

was agreed to with the following amendment:—

> "At a general meeting of the Society, after voting on a motion by a show of hands, the Chairman of the meeting or any ten voters present at the meeting may call for a postal vote on the motion which shall be decisive."

The scrutineers then presented the results of the ballot, and the following members were declared duly elected to serve on the Council for the two years ending March, 1928:—Captain P. D. Acland, Mr. Griffith Brewer, Captain G. T. R. Hill, Mr. H. B. Irving, Major A. R. Low, Mr. W. O. Manning, Mr. F. Handley Page, Major G. H. Scott, Mr. H. E. Wimperis and Mr. R. McKinnon Wood.

The scrutineers were thanked for their services and the meeting closed.

PROCEEDINGS

Sixth Meeting, First Half, 61st Session

A meeting of the Royal Aeronautical Society was held in the Society's Library at 7, Albemarle Street, London, on Thursday, November 12th, 1925, when a paper on "Some Problems in Aeroplane Structural Design" was read by Mr. H. B. Howard, Associate Fellow. Air Vice-Marshal Sir Sefton Brancker, K.C.B. (Chairman of the Society), presided.

Before calling upon the Lecturer to read his paper, Sir Sefton Brancker said: I have to introduce to you to-night Mr. Howard, of the Airworthiness Department of the Royal Aircraft Establishment. He is engaged upon the very interesting and important work of checking the airworthiness of all new civil aircraft and of many new military aircraft, on paper, and while actually being tested. He has to find out where their weaknesses are and where their design can be improved. It is very interesting and important work.

SOME PROBLEMS IN AEROPLANE STRUCTURAL DESIGN

BY H. B. HOWARD, B.A., B.SC., A.F.R.AE.S.

The present paper is the outcome of a request by the Secretary of the Society for a paper dealing with modern methods of aeroplane strength calculations. I much appreciate this opportunity of speaking before the Society on this subject, with which I have been associated in an official capacity for some years. I should also like to thank the Air Ministry authorities for permission to read the paper and for the loan of the slides which illustrate it. I need hardly add that any views contained therein are entirely an expression of my personal opinion.

In considering suitable material it seemed to me that the standard methods as now employed in strength calculations would form but tedious hearing in a lecture, and in any case would be familiar to many of my audience. I have therefore selected a number of particular problems that are illustrative of particular ponts, in the hope that their presentation here will promote useful discussion.

Before proceeding to these in detail I should like to outline briefly the general problem of aeroplane strength. This divides itself naturally into two parts, the determination, first of the external loads, second of the strength and reliability of the individual members of the framework.

So complex and variable are the external loads, arising as they do from air forces, ground forces, and the weight and inertia of the aeroplane itself, that to investigate all possibilities is a task of such magnitude that it could only be attempted as a piece of scientific research. For practical design purposes only a limited number of selected types of loading can be investigated.

These cases are arranged to be as comprehensive as possible, and it is found as the result of experience that aircraft complying with certain standards of strength for these will, with a fair degree of certainty, possess sufficient strength for those types of loading not specifically covered. At the same time it should not be forgotten that this is an article of faith rather than of reason, and all the more caution is needed in the original selection of, and subsequent modifications to, the specific cases.

The maximum loads which the structure will be called on to carry cannot be stated with certainty, as they depend primarily on how the pilot manipulates his controls. The maximum loads the pilot can impose are calculable, but these are greatly in excess of those he does impose. It is neither practicable nor necessary to make the aeroplane absolutely unbreakable at all speeds.

Experience and data from similar previous types will indicate in any particular case the approximate standard of strength needed. An important part of this experience is the result of accelerometer tests and I shall have occasion to discuss this source of knowledge in the latter part of the paper.

The human factor, however, introduces into the problem an uncertain element which can never be entirely eliminated, however complete our aerodynamic and structural knowledge may ultimately become.

On the purely structural side, a new and highly specialised branch of structural engineering has had to be developed. The ever present need for low weight, the extensive use of redundant space frames, the complex types of loading to which the separate members are subjected and other causes, have necessitated much extension and amplification of the theory of structures.

Many valuable contributions to this theory have resulted. The strength of standard types of construction can now be computed with very fair accuracy. The greater the accuracy however the longer the time taken, and some compromise is inevitable. In practice it is only by dint of small detail approximations and simplifying assumptions that the time occupied in structural analysis can be brought within reasonable dimensions. These approximations are arranged to be on the conservative side, *i.e.*, they tend to give too low a figure for the actual strength of members. It is therefore to be expected (and is confirmed by strength test results) that, on an average, the real is higher than the calculated strength.

This analytical complexity of aeroplane structures has an important bearing on their design. Calculation methods have their limitations, and general design considerations may indicate a type of construction which is either not calculable at all or only so with difficulty. This feature is a serious drawback to such types, and structurally speaking, the calculable type is preferable.

It may be said that resort to strength test can always be made; and strength testing is undoubtedly an invaluable weapon judiciously used. Like calculation, it has its limitations, though they are of a different nature. Apart from obvious limitations such as size, cost and complexity of loading, a strength test by itself is only evidence that that particular structure withstood a particular load. It gives no evidence as to how the strength will vary with variation in scantlings or material, nor as to how the design should be modified to increase the load carried by a given moment. The best solution seems to lie in a judicious blending of the two methods by which the best can be extracted from each, the strength test being used to check and supplement the results of calculation.

Viewing the problem as a whole it is hardly surprising that resort has had to be made so largely to empiricism and rule of thumb. In finding and fixing suitable standards, statistical methods have had to be used. The usual procedure has been to decide upon a suitable type of loading roughly representative of actual conditions, to calculate the strength of a number of aircraft under this type, and judge from a knowledge of which aircraft have proved satisfactory and which have not, what a suitable standard of strength should be. Rules framed on this basis have to be regarded as, in the first instance, on probation. They have not the immutable quality of a natural law. There is therefore need for constant watchfulness over their practical working in order to record any evidence indicating necessity for revision. A flexible and adaptable system of this kind is inevitable in a developing science such as aeronautics.

It must be admitted that a logical basis would be more satisfying. A little knowledge may be a dangerous thing, but it is better than a lot of guesswork. Where definite knowledge exists it seems but right to employ it so that as data increases structural design may rest more on fact and less on conjecture.

The particular points I now propose to deal with illustrate some of the general features mentioned above. They are as follow :—

I.—The standard cases taken for strength calculations.

II.—The load distribution over tapered wings. This has now been brought out of the arbitrary condition into the realm of more exact knowledge and exemplifies the advantages thereof.

III.—The staggered spar; another problem which has lately come to the fore and which forms an excellent example of that analytical complexity to which even quite innocent looking constructions may lead.

IV.—The present position in regard to accelerometer records as a point of primary importance in fixing the magnitude of the external loads.

I.—Specific Types of Loading Selected

The standard cases used at present will be found described in the latest report of the Load Factor Sub-Committee (R. and M. 776) and in the official Handbook of Strength Calculations and I do not propose to discuss them in detail here. They are for the most part simple and straightforward and the reasons for their inclusion are clear enough. There are, however, a few small points which I hope I shall be pardoned for mentioning as experience has shown me that misapprehension is liable to arise in connection with them.

Thrust and Inertia Forces

The first is that of the formula laid down for calculating the thrust of the engine when combined with air loads. The formula is as follows :—

$$\text{Thrust} = 2 \times 550 \times \eta \times \text{H.P.} / V \sqrt{\tfrac{1}{2}N}$$

N is the C.P. forward load factor and V the stalling speed of the aircraft, η is the propeller efficiency. The implicit assumption here is that the aircraft is flying horizontally at speed $V \sqrt{\tfrac{1}{2}N}$ and the nose is then pulled up suddenly till the wings are at stalling angle. The load on the wings rises to $N/2$ times normal and the thrust has half the value given by the formula. As a load factor N is required both thrust and air loads have to be doubled.

In this connection I might mention that the horizontal inertia forces have to be calculated in order to bring the force system on the aeroplane into equilibrium. If we suppose both air load and weight multiplied by N the lift continues to balance the weight, but the drag is only partially balanced by the thrust, which obviously cannot reach N times normal value. Balance is achieved by a forward inertia force F which is determined as follows : (Fig. 1.).

$$F = ND - T$$

In this figure the thrust is taken horizontally along the wind direction for convenience, L and D are the *total* air lift and drag on the aircraft, for the attitude speed, *i.e.*, the speed of horizontal flight corresponding to the attitude of the aircraft, T is the engine thrust, F is the resultant inertia force forwards, being the resultant of all the inertia forces on the separate component masses in exactly the same manner as the weight is the resultant gravitational force.

For the engine off case T is zero and D must include the windmill drag of the propeller.

These inertia forces are particularly important in designs containing heavy concentrated masses such as engines, petrol tanks, etc., carried in the wings.

DIAGRAMMATIC REPRESENTATION OF FORCES INTRODUCED BY A SUDDEN CHANGE OF ATTITUDE.

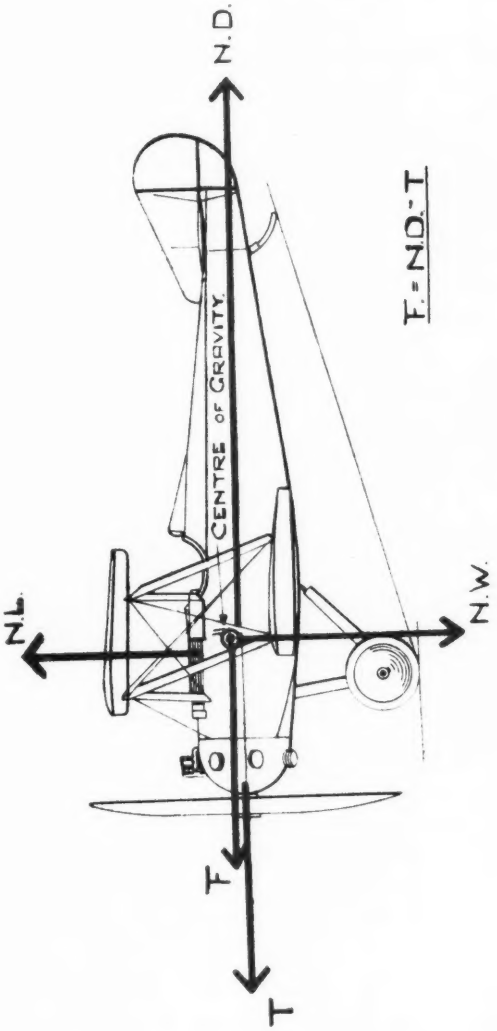


Fig. 1.

Limiting Nose Dive Case

The question is often asked "Why take the limiting nose dive case for aircraft which will obviously never reach such a condition?" In fact it was pointed out in quite the early days of civil flying that if a passenger machine dived vertically all the passengers would be in a heap in the nose.

The reason for its continued inclusion is that it is intended to cover not only the limiting dive itself, but also dives at speeds less than the terminal which will produce loads of a generally similar type. The characteristic features of the case are a down load over the front part of the wing and a heavy down load over the tail and it is not necessary to reach the terminal speed before this general type of loading is produced. In addition the limiting nose dive covers, in some measure, the effects on the wings of down gusts at ordinary flying speeds. Such gusts may easily reduce the angle of incidence momentarily to zero or even to a negative value and a transitory down load comes into play.

Inverted Flight Case

An inverted flight case for such aircraft as are likely to perform that manœuvre has lately been introduced, and a few words of explanation thereon may not be out of place.

On ordinary wing sections the effect of inversion is to increase the drag for a given lift coefficient and to reverse the manner of movement of the centre of pressure, that is, as the lift coefficient increases negatively the centre of pressure moves backwards from in front of the leading edge to a position in the neighbourhood of one third chord.

For strength calculations this latter position, corresponding to a fairly high negative lift coefficient, was chosen in order to check the strength of the rear truss as well as that of the front. The high drag is represented by taking a force in the direction of the chord of one-tenth the normal force, corresponding for an angle of attack of $-15°$, to a lift/drag ratio of about 2.6 only.

The load factor can be lower than in normal flight as the lift coefficient obtainable is much lower, and owing to the greatly increased drag the aircraft is less manœuvrable upside down.

II.—Tapered Wing Monoplanes

As an example of the advantages to be derived from the use of more exact knowledge when available, I propose to deal with the question of load distribution over tapered wings. This type of construction has received considerable attention in this country during the last few years, and this point is one of particular interest at the present time. Fortunately, the development of this type has coincided with that of the vortex theory of airflow and this theory has been adapted to the needs of this problem; the mathematical basis of the method is given by Mr. H. Glauert in R. and M. 824, where examples will be found which indicate very satisfactory agreement between theory and experiment. Prior to the existence of the method these wings were calculated on what is usually called the "strip" theory, and I shall refer later to the difference between the two.

The essential characteristic of these wings is that the chord and the angle of incidence may vary along the span. It is easy to see that this may have curious effects on the shape of the load distribution. Usually the tip is at a less incidence than the root, *i.e.*, there is wash out at the tip; a reduction or even a reversal of load is to be expected in that region.

Fig. II. shows some typical curves for a wing with 5 degrees wash out, *i.e.*, the tip is at $5°$ less incidence than the root. The curves represent $12°$, $4°$, $3°$

LOAD DISTRIBUTION CURVES FOR STRAIGHT TAPERED TWISTED WING.

(As Used in Strength Calculations).

Tip Chord=.5 Root Chord. Incidence 5° Less at Tip than at Root, Varying Linearly Along Span.

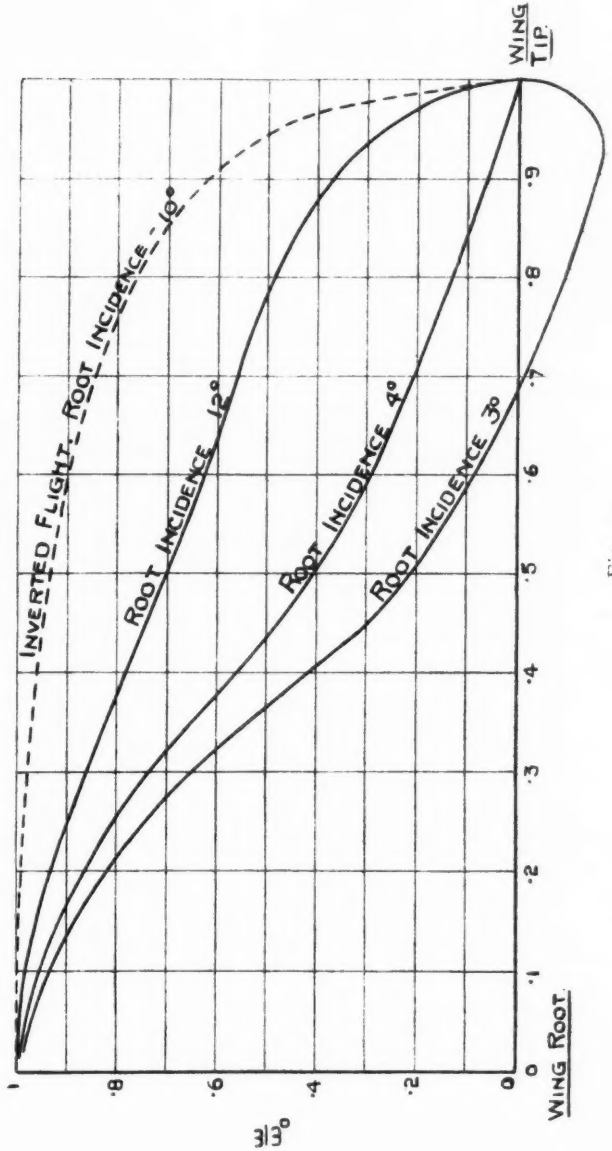


Fig. 2.

and $-10°$ angle of incidence at the root. The reduction of loading towards the tip as the incidence decreases is most marked. For the negative angle, which would correspond to inverted flight, the load tends to pile up on the outer portion of the wing, a phenomenon of importance in strength calculations for this case. I shall describe further on a rapid method of drawing these curves for simple cases.

Throughout the following work the term angle of incidence is used to denote the angle between the flight path of the aeroplane and the no-lift line of the section concerned. The lift coefficient-angle of incidence curve can be taken as a straight line over the greater part of the range and the lift coefficient is thus proportional to the angle of incidence.

By a twisted wing I mean a wing in which the no-lift lines of the separate sections do not lie in the same plane. Thus a wing in which different aerofoils sections are used along the span may be aerodynamically twisted, although not appearing twisted to the eye. Tapered wings fall naturally into two classes, the untwisted and the twisted. For the former type the shape of the load distribution curve is independent of the angle of incidence, *i.e.*, in such a wing all the curves shown in Fig. II. would have been the same shape. But when the angle of incidence varies along the span the shape of the curve changes with incidence as illustrated. The twist may be due, of course, either to the aerodynamic design or to elastic distortion of the structure under load.

Developments of the Prandtl vortex theory now enable us to compute these effects for angles of incidence below the stall with an accuracy which gives quite good agreement with observed results in the wind-channel.

When these methods come to be applied to practical strength calculations considerable condensation and simplification is possible.

In outline, the method consists in selecting a certain number (say n) of points along the span and then writing down n simultaneous equations. These equations determine the n coefficients of the first n terms of a Fourier's series from which the aerodynamic properties of the wing are deduced. The larger the number of points taken the greater the accuracy of the results. Usually four points give sufficient accuracy for practical purposes. To take more than four greatly increases the labour, as the solution of a large number of simultaneous numerical equations is very lengthy. All the subsequent work is based on a four term analysis.

The first consideration is the plan form of the wing. It has been shown that the most efficient plan form aerodynamically is the elliptical, but for constructional reasons tapered wings are nearly always built with the leading and trailing edges straight, and I confine my attention here to the straight tapered type. Wings with straight edges except for slight rounding at the tips may usually also be included in this category.

I have condensed the work to a very simple form by which the load distribution can be obtained for any wing of this type in a very short time without elaborate calculations.

The curves throughout refer to wings of aspect ratio 6 and it is assumed that the slopes of the curves connecting lift-coefficient and angle of incidence (in radians) for all the separate sections are equal to π. These values will hold fairly closely for the majority of wings and slight departures therefrom will not materially affect the shape of the load distribution curve.

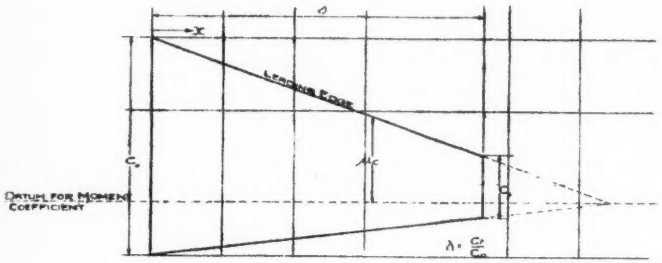
As explained above, these wings can be conveniently divided into the untwisted and the twisted types.

Fig. III. shows the shapes of load distribution curves for untwisted straight tapered wings for different ratios of tip chord to root chord. This ratio is denoted by λ in the figure, the appropriate value being marked against each

curve. The curves are only meant to show the general shape and are plotted to have the same ordinate at the root.

Unfortunately for the "stress merchant," wings are hardly ever designed to have constant incidence and to be of the same aerofoil section throughout. Fig. IV. provides curves for the twisted wing case. The figure is self-explanatory and gives the value of $K_L C/C_0$ (C_0 is the root chord, C the chord at the point), for seven points along the wing. They are really the curves of Fig. III. cross-plotted

LOAD DISTRIBUTION CURVES OF UNTWISTED STRAIGHT TAPERED WINGS.



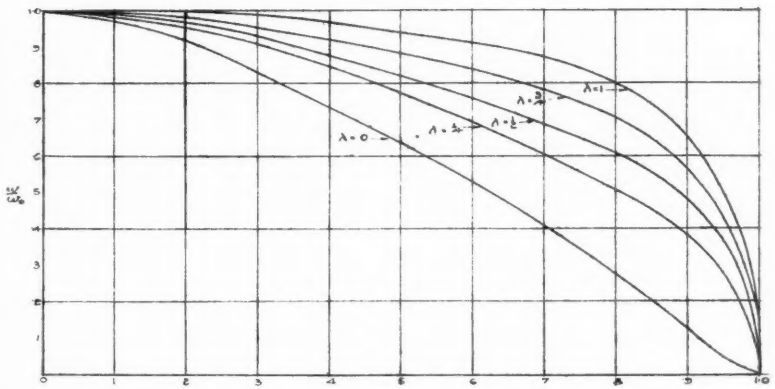


Fig. 3.

for constant fractional distances from the root, with a further family of curves giving corrections for twist. The procedure is as follows :—

1. Read the ordinates of the seven curves for the appropriate value of λ.
2. Multiply these ordinates by the root incidence (from no lift) in radians.
3. Add the correction for twist from the lower curves. The angle of twist, ϕ radians, is the difference between the no-lift angles of the root and tip sections.

If the angle of incidence increases towards the tip (wash-in) ϕ is positive. In preparing these curves it is assumed that the twist varies linearly along the span. Some further details of the method are given in Appendix I. where simple expressions for the bending moment at the root and pitching moment are given.

Comparison with "Strip" Theory

Previous to the development of the above method it has been customary to treat these wings by what is usually described as "strip" theory. It was assumed that the lift on each elemental strip was independent of the surrounding strips and for a given air speed varied directly as the chord and angle of incidence. This method is still sometimes used, and I have prepared some curves to show that considerable errors may thereby be introduced.

Broadly it may be said that any given change in chord or angle does not produce so big an effect as "strip" theory would indicate, that is, the "strip" theory always overdoes it. For example, an untwisted wing tapered to a point at the tip would on the "strip" theory have a simple triangular load curve, whereas actually the curve has a marked convexity upwards, that is, the load does not fall away so sharply. Similarly the change of load due to twist is not so great as "strip" theory gives. Figs. V., VI. and VII. illustrate these effects.

COMPARISON OF STRIP AND PRANDTL THEORIES.

(The Comparison is made at the Same Mean Lift Coefficient).

Variation in Position of C.P. Along Span with Ratio of Tip Chord to Centre Chord for Untwisted Straight Tapered Wings.

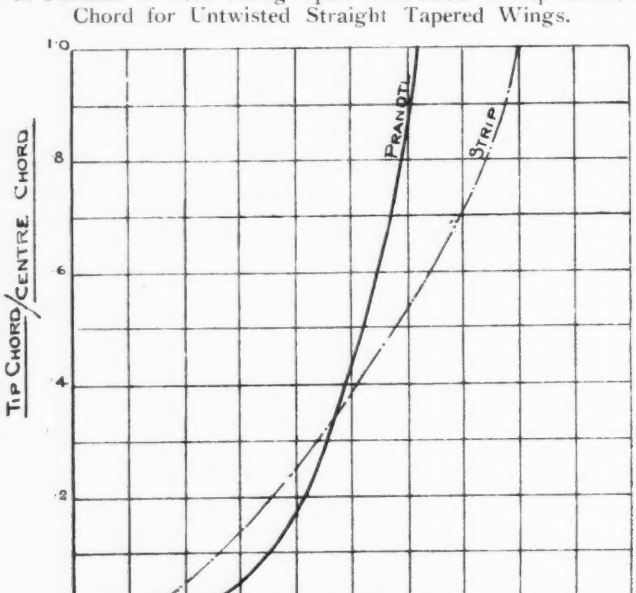


Fig. 5.

Note on the Use of Stalloy Ring Stampings for Magnetic Shielding Purposes. By D. W. DYE, B.Sc.
The Design and Use of an Air Condenser for High Voltages (*continued*). By E. H. RAYNER, Sc.D.
Photoelectric Photometry (*concluded*). By THE RESEARCH STAFF OF THE GENERAL ELECTRIC COMPANY, LTD.
The Measurement of Current and Voltage in Alternating Current Bridges. By L. HARTSHORN, A.R.C.S., B.Sc., D.I.C.
Tabular Information on Scientific Instruments: III. Resistance Boxes.

VOL. III, No. 4. JANUARY, 1926

The Fabry and Perot Parallel Plate Étalon. By W. H. J. CHILDS, B.Sc.
The Design and Use of an Air Condenser for High Voltages (*concluded*). By E. H. RAYNER, Sc.D.
An Automatic Device for Focussing the Telescope of a Tacheometer. By H. KOURKÈNE.
A Low Speed Vane Anemometer. By E. OWER, A.C.G.I., B.Sc.
An Application of the Diode to the Measurement of A.C. Voltages. By JAMES TAYLOR, M.Sc., A.Inst.P.
A Simple Method of Measuring the Capacity and High Frequency Loss of a Condenser. By LEONARD SAYCE, M.Sc., A.I.C.
New Instruments.
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Tabular Information on Scientific Instruments: IV. Wheatstone Bridges.

Test Room and Workshop Notes, Correspondence, Reviews, Publications received, &c.

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JOURNAL OF SCIENTIFIC INSTRUMENTS

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WITH THE CO-OPERATION OF THE NATIONAL PHYSICAL LABORATORY

EDITOR: C. V. DRYSDALE, O.B.E., D.Sc., M.I.E.E., F.INST.P., F.R.S.E.

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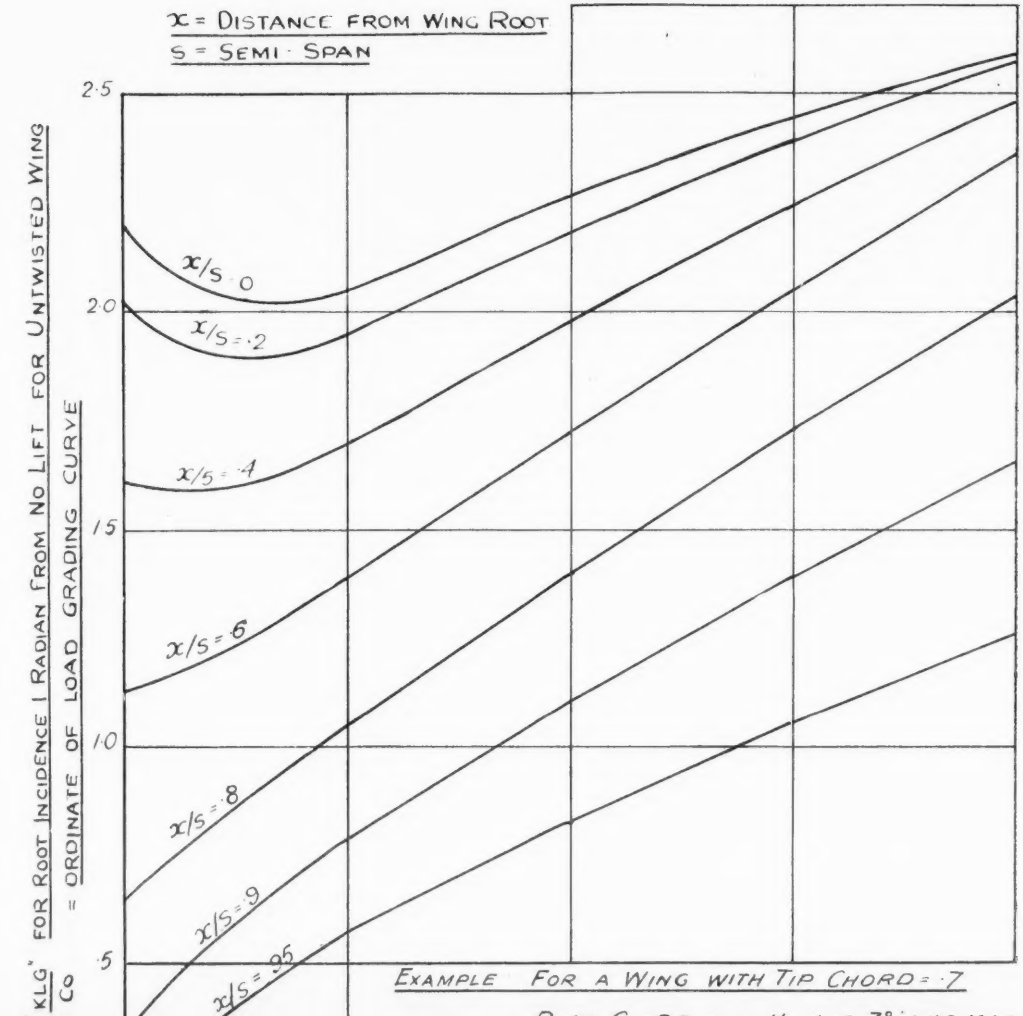
STRAIGHT TAPERED WING WITH TWIST VARYING LINEARLY FROM ROOT TO TIP LOAD DISTRIBUTION CURVES FOR CONSTANT X/S.


x = DISTANCE FROM WING ROOT
s = SEMI-SPAN
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1·5
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x/s = 0
x/s = ·2
x/s = ·4
x/s = ·6
x/s = ·8
x/s = ·9
x/s = ·95
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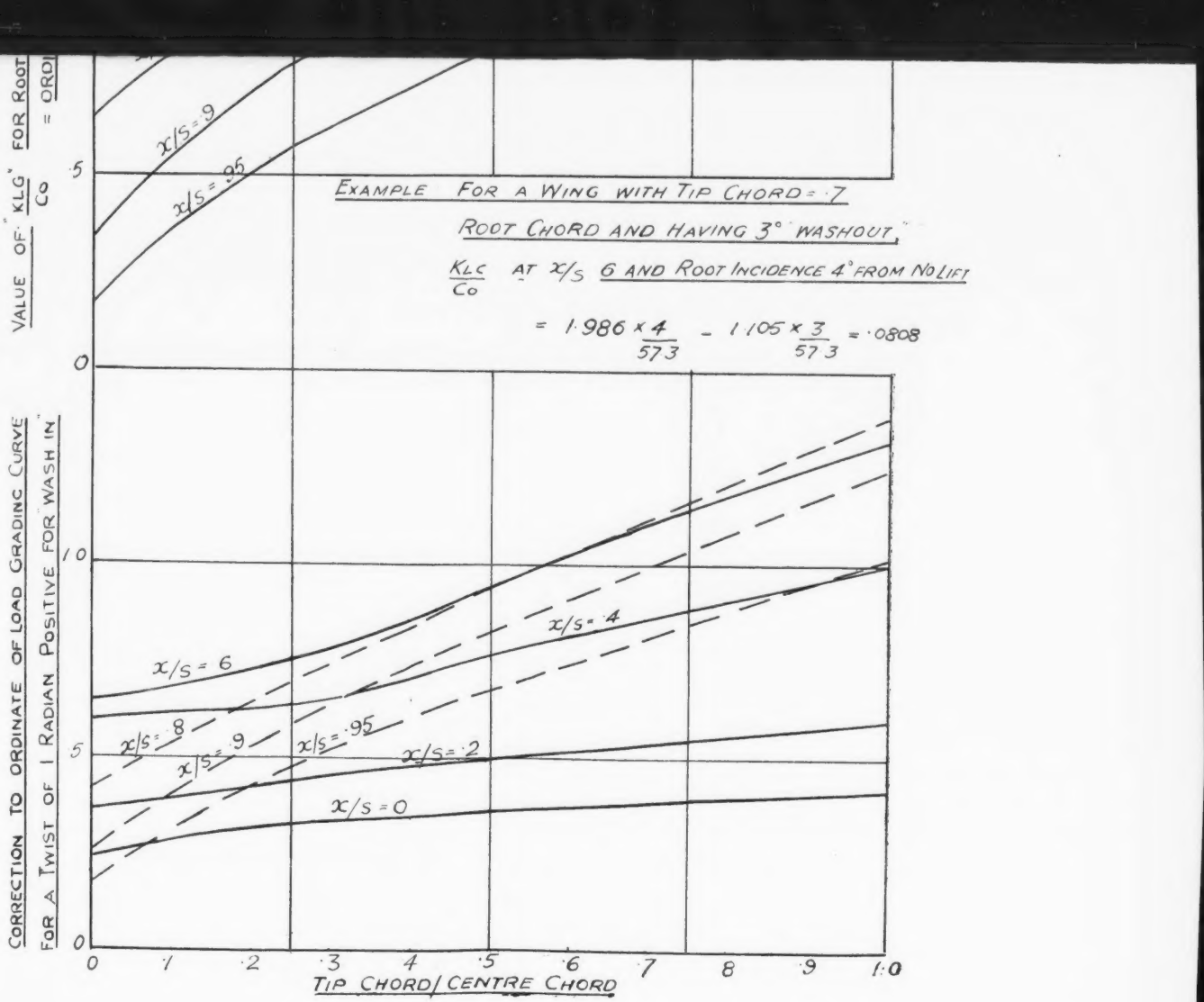
KLG' FOR ROOT INCIDENCE 1 RADIAN FROM NO LIFT FOR UNTWISTED WING
Co = ORDINATE OF LOAD GRADING CURVE


CORRECTION TO ORDINATE OF LOAD GRADING CURVE FOR A TWIST OF 1 RADIAN POSITIVE FOR WASH IN
VALUE OF "KLG" FOR ROOT
Co = ORDI
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EXAMPLE FOR A WING WITH TIP CHORD = ·7
ROOT CHORD AND HAVING 3° WASHOUT.
KLC/Co AT x/s 6 AND ROOT INCIDENCE 4° FROM NO LIFT
= 1·986 × 4/57·3 − 1·105 × 3/57·3 = ·0808
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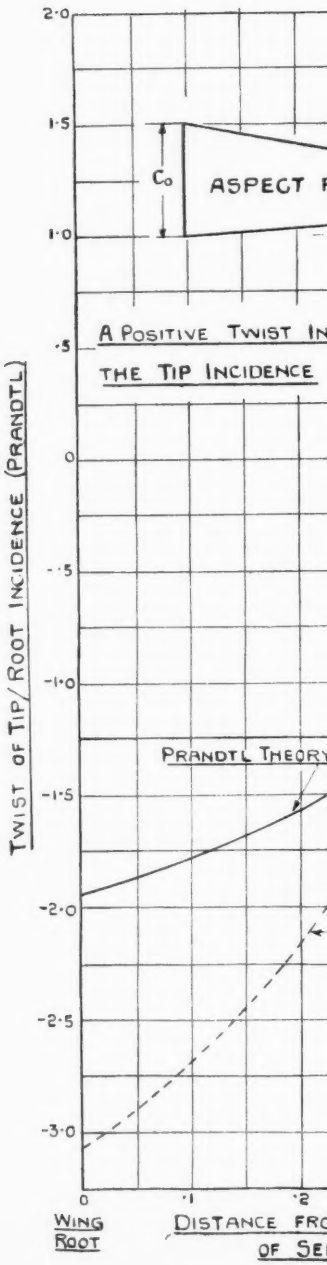
TIP CHORD/CENTRE CHORD

Fig. 4.

Fig. 4.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A POSITIVE TWIST IN
THE TIP INCIDENCE
TWIST OF TIP/ ROOT INCIDENCE (PRANDTL)
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COMPARISON OF STRIP AND PRAN

(The Comparison is made at the Sam

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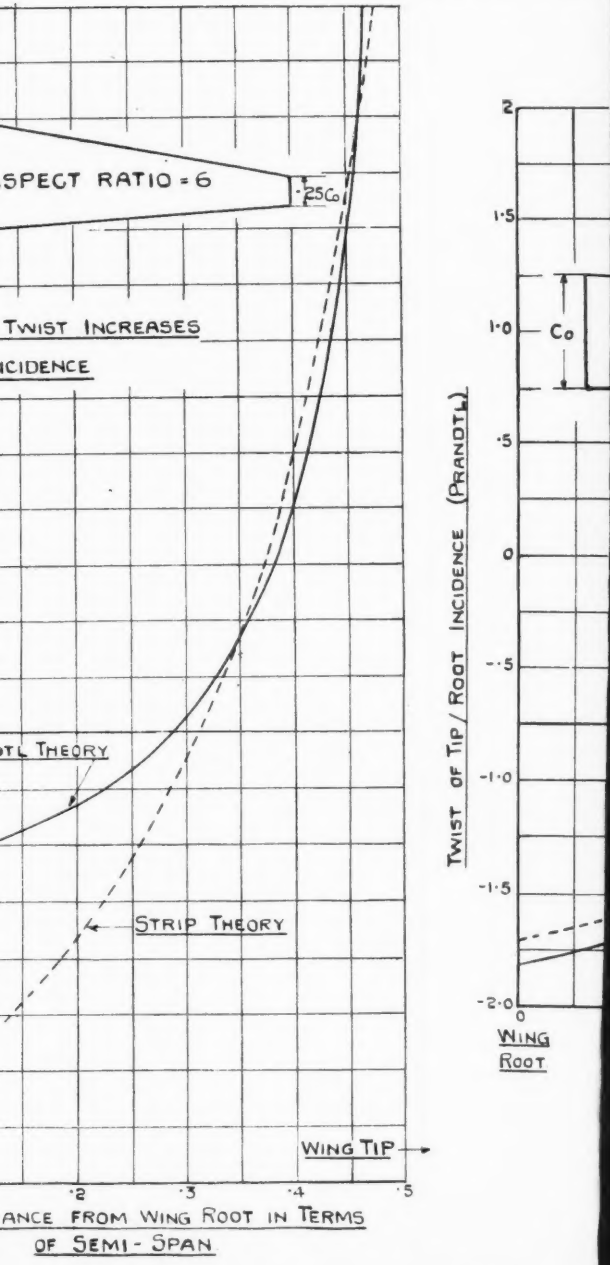

Fig. 6.

IP AND PRANDTL THEORIES.
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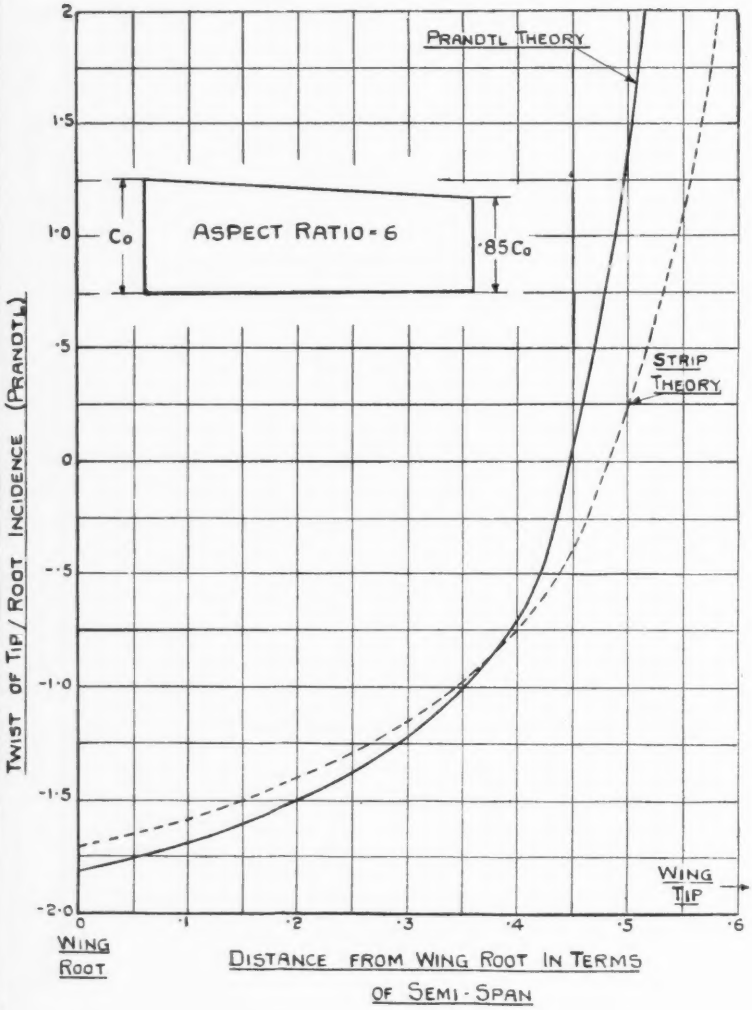


Fig. 6.

Fig. V. shows the difference of root bending moment between the two theories for an untwisted wing. The ordinates of this curve are the ratio Tip Chord/Centre Chord, the abscissæ are distances of the resultant centre of pressure from the root of the wing as a fraction of the semi-span. As the two curves are plotted for the same total lift the root bending moment is proportional to this quantity. At a particular value Tip Chord/Centre Chord namely .34, the two theories are coincident. For greater values the "strip" theory gives too

COMPARISON OF STRIP AND PRANDTL THEORIES.

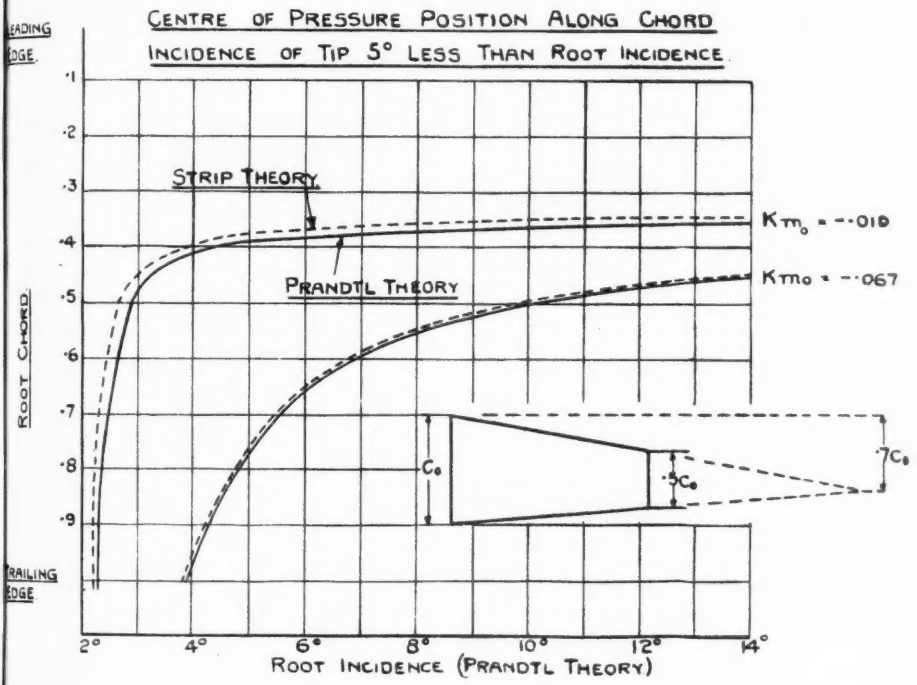


Fig. 7.

high a bending moment and for smaller values too low. This is in accordance with the general tendency.

This comparison will hold for all angles of incidence as the shape of the load distribution curve remains the same for the untwisted wing.

In addition to variations of root bending moment the two theories will, of course, give different shapes of bending moment curve along the span. The root bending moment is chosen simply to give an idea of the order of magnitude of the errors involved.

When we come to the twisted wing a curious phenomenon appears. I give curves for two values of λ, .85 and .25 (Fig. VI.). With these curves the abscissæ are as before fractional distances of the resultant centre of pressure

from the root. The ordinates are the ratios of twist to root incidence (ϕ/α). The comparison is made at the same total lift. For this condition the two theories do not give the same value of root incidence. The value of root incidence taken for the curves is that given by the vortex theory. This ratio (ϕ/α) may for the low incidences reach values as great as ± 2; a negative value is the more likely. On the larger tip chord, at zero twist the " strip " theory gives the C.P. too far out; taking as an example a negative twist (say $\phi/\alpha = -1.5$) the " strip " theory brings the C.P. too far in, *i.e.*, as before it has overdone the effect of twist.

On the small chord ($\lambda = .25$) at zero twist the " strip " theory brings the C.P. too far in; it has overdone the effect of chord reduction and made the load over the tip too small. At negative twist, as it has made the load on the tip too small, it underestimates the effect of twist, *i.e.*, it does not bring the C.P. far enough in. For low angles of incidence it is manifest that the " strip " theory gives wildly erroneous results.

In Fig. VII. a similar comparison is shown for centre of pressure along the chord. The centres of pressure plotted as ordinates are the mean centres of pressure for the whole wing as a fraction of the root chord, and so are not directly comparable with one's ordinary ideas of where a centre of pressure of a wing should be. Curves for two aerofoils are shown, one having a low no-lift pitching moment ($-.010$) the other with a high no-lift pitching moment ($-.067$). The abscissæ are actual angle of incidence for a wing with 5° wash-out. A specific case was chosen as the form of the algebraic expressions was such that a condensed general comparison could not easily be made. It is clear that " strip " theory will introduce a further discrepancy which for this particular wing is most marked at low angles of incidence.

I have gone into this comparison at some length as I particularly wish to emphasise that for strength calculations the " strip " theory is not satisfactory. The results are too unreliable, and with the more exact theory reduced for the majority of practical cases to at least as simple a form for this purpose, its use can definitely be abandoned.

Lift Coefficient

The lift coefficient curve along the span can immediately be determined from the load distribution. The theory applies only so long as stalling has not begun at any point. For the centre of pressure forward case we require to determine the angle at which stalling begins. Strictly this can only be done by trial and error—*i.e.*, we must draw a series of lift coefficient curves for varying angles of incidence and find when stalling is reached at any point.

The theory gives no indication of the maximum lift coefficient, and this can only be obtained from channel tests.

A peculiar feature of tapered wings is worth noting here, namely, that the maximum ordinate of the lift coefficient curve along the span does not necessarily occur at the centre, as in the uniform wing, but in the untwisted wing at a point progressively further from the root as the tip chord is reduced. Fig. VIII. shows a series of curves illustrating this point. In practice it will be sufficiently accurate for strength purposes to take a curve corresponding to a fairly high value of root incidence, about 12°.

The load distribution curve for the complete wing having been determined, the steps to follow will be dictated by the nature of the construction employed, and should present no serious difficulty. The centre of pressure at points along the span can be determined immediately from the lift coefficient at each point. The relation between pitching moment and lift coefficient for any section is independent of the position of that section and of the aspect ratio of the wing, so that the distribution of centre of pressure along the span follows immediately.

Distortion of Cantilever Wings

Under the action of the air load the cantilever wing both bends and twists. The bending, it may be presumed, will not appreciably affect the air load, but the twisting will considerably change the distribution. Thus, if we imagine the root chord kept at a constant angle of incidence and suppose the air load increased

STRAIGHT TAPERED UNTWISTED WING.

Variation of Lift Coefficient Along Span.

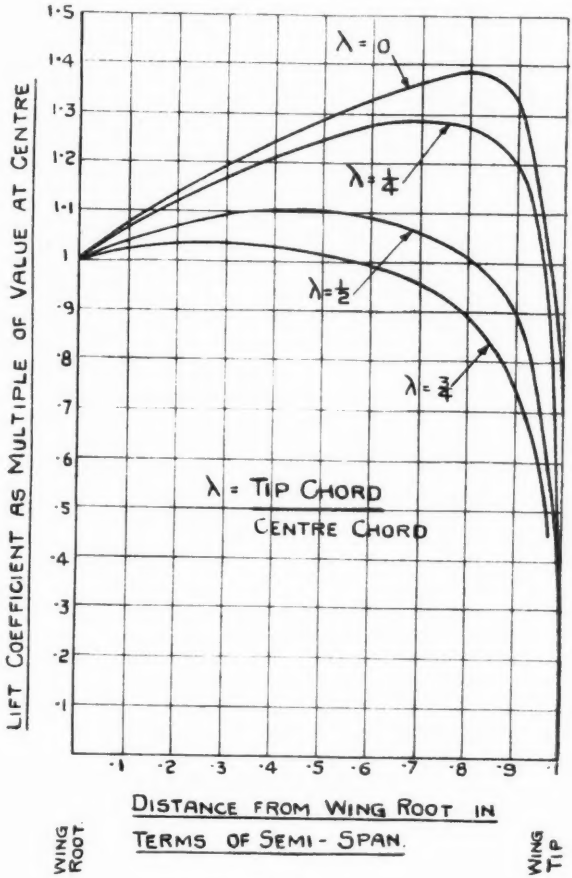


Fig. 8.

by an increase in forward speed, the shape of the load distribution curve will change as the wing distorts. A similar effect is of course present in a biplane structure, but owing to the far greater torsional rigidity of this type, its effects are negligibly small. Unfortunately the same cannot immediately be said of the cantilever monoplane and it becomes necessary to inquire into the magnitude of this effect.

It has been shown above how twist of a given type affects the loading, but the converse problem of finding what twist a given loading will produce is one of far greater length and complexity. Even if we make simplifying assumptions the final state of the wing can still only be found by "trial and error," owing to the mutual interaction of loading and distortion.

The main difficulty in the exact problem lies in finding the necessary elastic constants. Consider one of the simplest cases, the two-spar wing. If the ribs had no stiffness the spars would deflect without twisting, and the spars themselves would carry no torque. But owing to the rigidity of the ribs the spars have to twist, and therefore, owing to their torsional rigidity, a bending moment is thrown on to each rib and equal and opposite shear forces on to the two spars. Briefly, the effect of the stiffness of the ribs and torsional stiffness of the spars is to transfer load from one spar to the other, the transference tending to equalise the deflections, at the same time each spar carries a torque varying along its length.

If this effect be neglected the twisting can be fairly easily approximated to by ordinary methods for determination of spar deflection. The approximation is definitely pessimistic—*i.e.*, the twists obtained will be greater than those actually occurring.

It might be of interest to mention here a very rapid method for obtaining approximate spar deflections and wing twist on a two-spar wing. The method makes the quite simple assumption that the spar is of uniform strength throughout—*i.e.*, that the maximum fibre stress is constant. This will not be very greatly in error except in the neighbourhood of the tip, where the spar is certain to be relatively stronger than at the root. As, however, the root sections have a far greater influence on the deflection, the assumption is quite reasonable as a first approximation.

With this assumption the deflection of the spar at any point depends only on the shape of the spar in side elevation and on the elastic constants for the material employed. The mathematics of the method are quite simple and are given in Appendix II., where it is shown that the tip deflection is given by the expression

$$\Delta = s^2 f m / 2 h_0 E$$

where

Δ = tip deflection,
s = semi-span,
h_0 = semi-depth at root,
f = maximum fibre stress,
E = Young's modulus,

and m is a purely geometrical function of the wing. Values of m for different shapes of spar are shown in Fig. IX. plotted against ratio of height at tip to height at centre. It is noticeable that a concave shape of taper gives a greatly increased tip deflection. The value $m = 1$ corresponds to the spar of uniform depth throughout. The curves of this figure may, if required, be used to determine the deflection at any point other than the tip by using, instead of s in the above formula, the appropriate distance from the root and reading the value of m from the curve for the appropriate ratio of height to height at root.

This formula can be used to compare the relative flexibilities of different materials. Thus, if we imagine a number of spars differing only in the materials used, the values of f/E will determine their relative flexibilities. These values are given in ascending order of magnitude for common aircraft structural materials in Table I. The value of f taken is that used as the maximum allowable stress for purposes of load factor calculations.

TABLE I.

Material.	Value of $f/E \times 10^3$.
28-ton steel	2.06
45-ton steel	3·31
Duralumin	3·75
Grade A Spruce	3·77
Grade B Spruce	3·93
65-ton steel	4·78

DEFLECTION OF CANTILEVER SPARS OF UNIFORM STRENGTH.

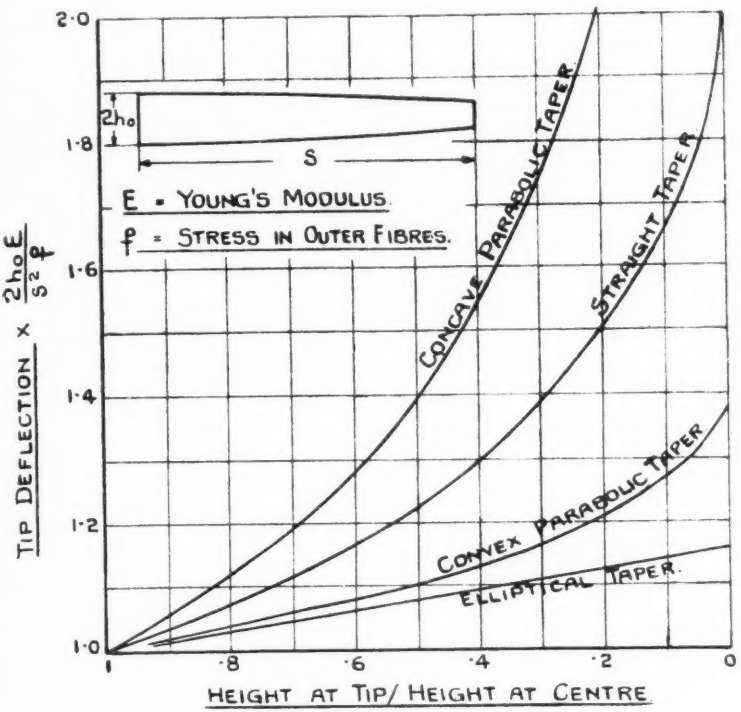


Fig. 9.

Young's modulus is very nearly constant for all aircraft structural steels, so the steel flexibilities vary as the stress.

Application to Twist of a Cantilever Wing

With the approximation indicated above, *i.e.*, neglect of rigidity of rib and torsional stiffness of spars, the above method can clearly be used to estimate the twisting of a cantilever wing. The angular distortion at any point is simply

$$\Delta_F - \Delta_R / ac$$

Δ_F and Δ_R being the deflections of the front and rear spars and ac the distance between them, c being the chord.

For a straight tapered wing in the notation of Appendix II. the twist at the tip is given in radians by

$$\theta = (m/2E)\,(c_o/h_o)\ \{ A^2 (1+p')^2/16ap' \}\ (f_F - f_R)$$

This formula assumes that the taper in plan is equal to the taper in elevation. The values of θ calculated from it may be quite large. Thus taking the following conditions :

Tip chord/root chord, .4,
Aspect ratio $= A = 6$,
Material : Grade B Spruce,
Depth of spar : $\frac{1}{8}$th chord at root,
Spar spacing $= a = \frac{1}{2}$ chord,
Centre of Pressure at .5 chord,
$(f_F - f_R)$ = difference of maximum fibre stresses on front and rear spar at unit load = 700lb./sq. in.,

then

$$\theta = 7^\circ.8$$

Actually the twist would not reach so high a figure since the method takes no account of the reduction in loading as the wing twists. But it is clear that effects by no means negligible may be produced by elastic distortion.

III.—Staggered Spars.

I referred earlier to the analytical complexity of many aircraft structural problems and an excellent example of the demands made by aeronautics on the theory of structures is afforded by the staggered spar.

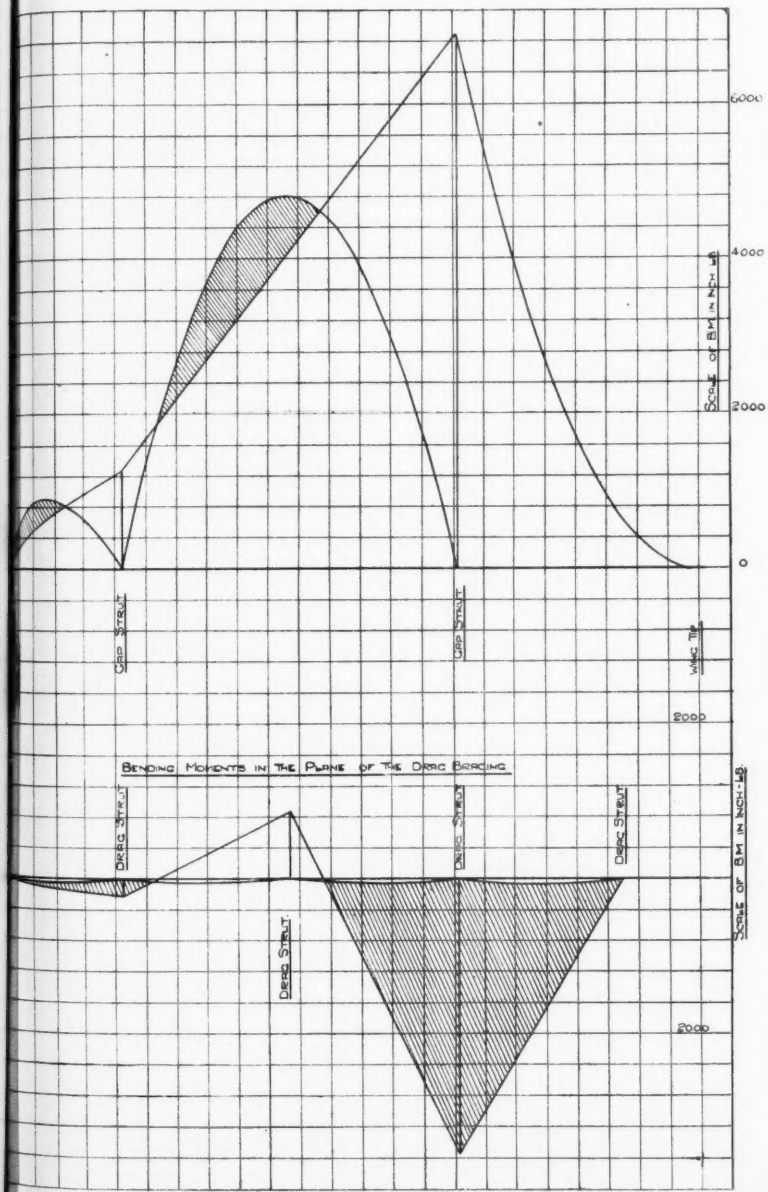
Many designers find that the fitting design and manufacture of wings having large stagger is much simplified if the sides of the spar are brought parallel to the plane of stagger. Special methods become necessary for calculating the stresses of spars of this type. I do not propose to discuss these in detail, but should like rapidly to indicate their main features. A short note on this subject by Dr. Hilda Hudson will be found in the issue of the Aeronautical Journal for October, 1921, and the mathematical theory has been extended by Mr. L. G. Brazier.

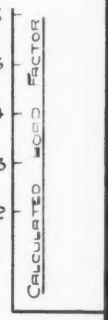
I suppose for ease of reference that the chord is horizontal and that the air lift and drag are respectively vertical and horizontal. We then have the following points to consider :

1. Staggered spars are subjected to what is known in the theory of structures as unsymmetrical bending, *i.e.*, neither of the principal axes of the spar lies in the plane of bending. Such a spar will, if supported only at the ends, deflect not only in this plane but also at right angles to it. If this deflection at right angles be resisted, horizontal moments will be introduced. For example, consider the moments due to lift forces. Under these the spars tend to deflect not only vertically but also in the drag plane. This deflection is resisted by the drag bracing and concentrated horizontal loads are thrown on the spars at the drag nodes. The result of this mutual interaction is that vertical and horizontal moments cannot generally be determined separately. The three-moment equation for vertical moments includes drag moment terms and *vice versa*. The number of simultaneous equations to be solved is much larger than for the normal case.
2. In the drag plane the front and the rear spars are constrained to move together by the ribs so that the loading and elastic properties, including two moments of inertia and the product of inertia of both spars, have

ng Moments in a Plane at Right Angles to the Plane of the Drag Bracing.
Top Rear Spar. C.P. Back.

B.M. Producing Convexity Upwards/Rearwards are Shaded.





EFFECT OF STAGGER ON SPAR STRESSES.

of the Drag Bracing.

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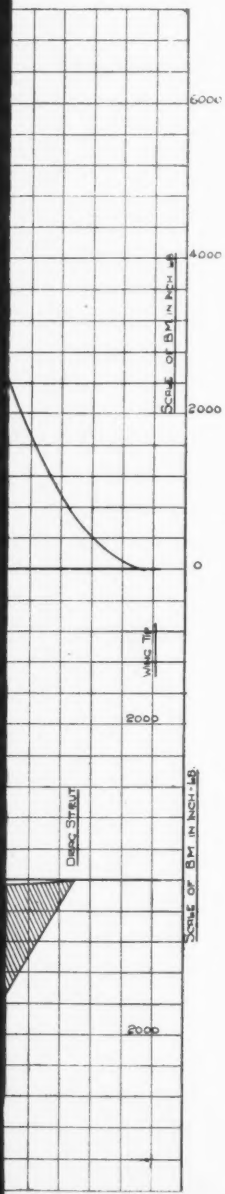
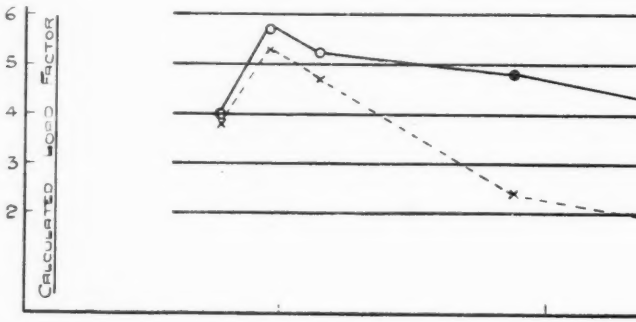




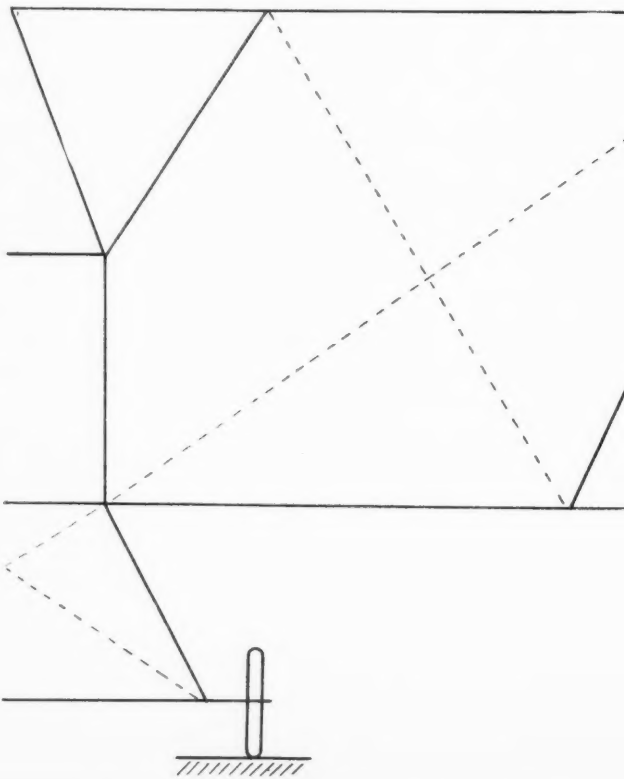
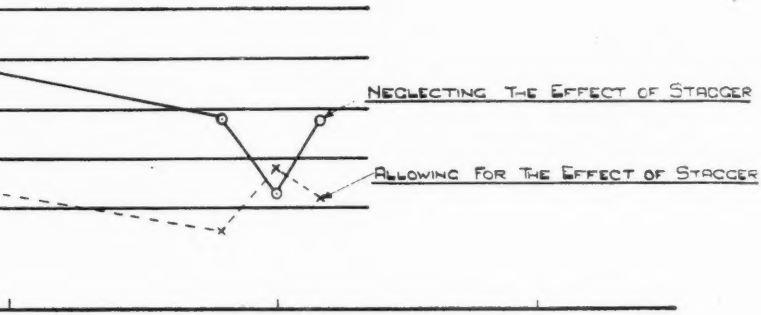
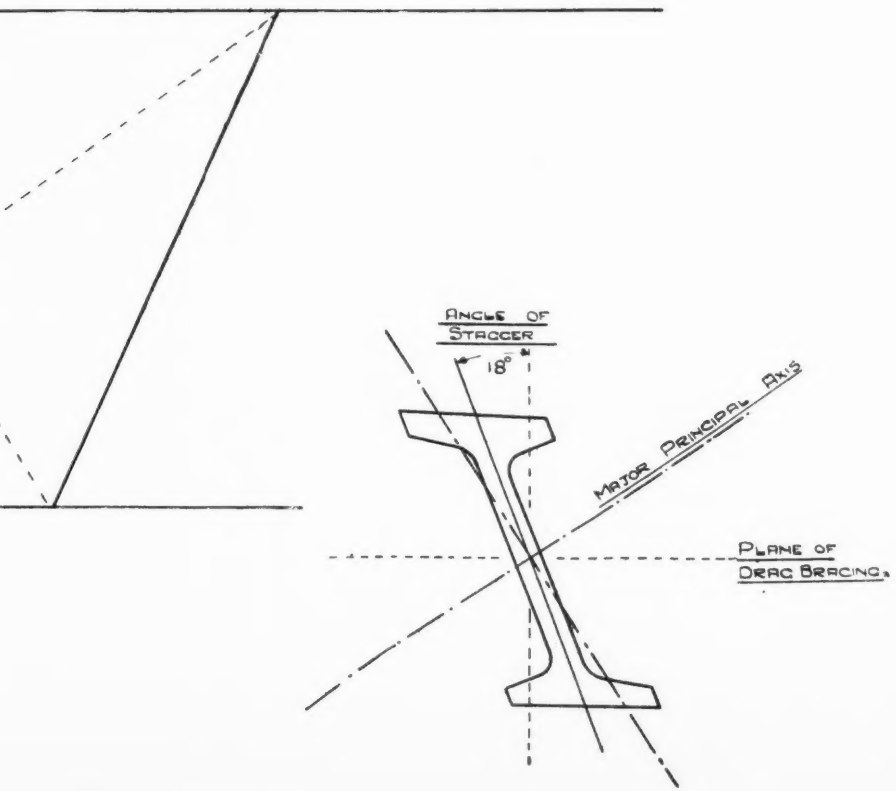


Fig. 10.


NEGLECTING THE EFFECT OF STAGGER
ALLOWING FOR THE EFFECT OF STAGGER


ANGLE OF STAGGER
18°
MAJOR PRINCIPAL AXIS
PLANE OF DRAG BRACING.

STRAIGHT TAPERED WINGS WITH TW

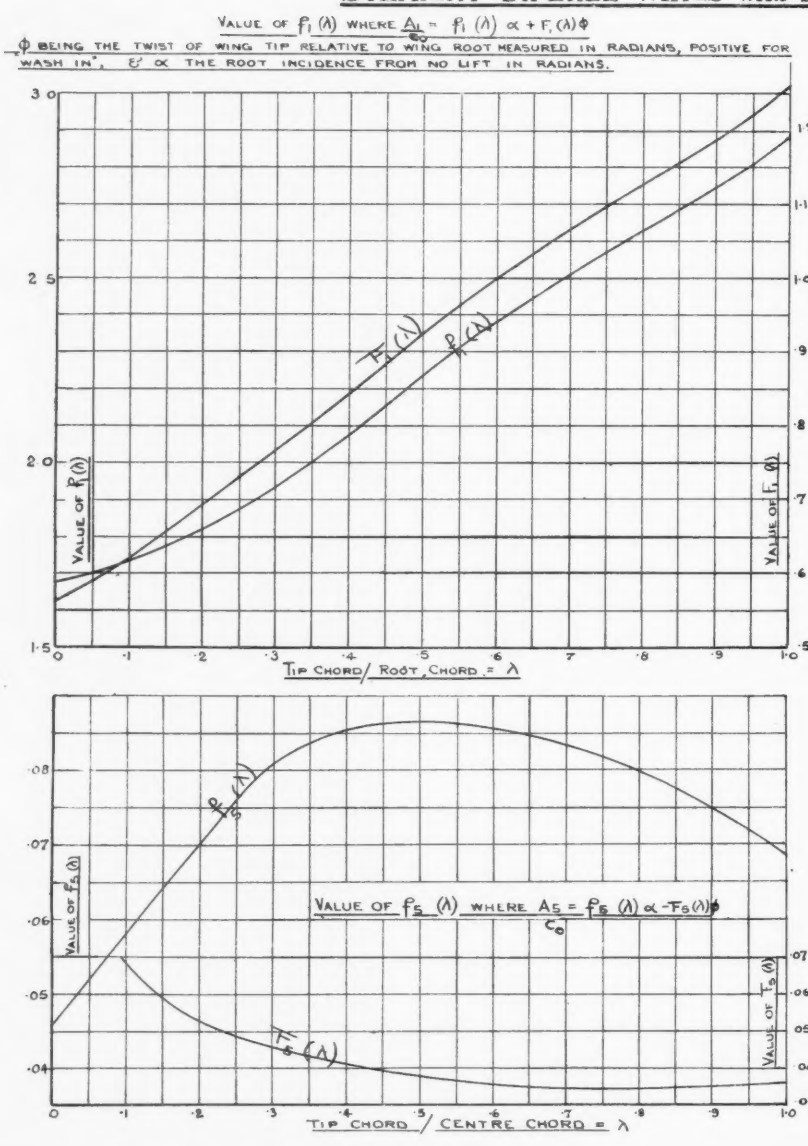

VALUE OF $f_1(\lambda)$ WHERE $\frac{A_L}{c_0} = f_1(\lambda)\alpha + F_1(\lambda)\phi$
ϕ BEING THE TWIST OF WING TIP RELATIVE TO WING ROOT MEASURED IN RADIANS, POSITIVE FOR WASH IN, & α THE ROOT INCIDENCE FROM NO LIFT IN RADIANS.
VALUE OF $f_1(\lambda)$
VALUE OF $F_1(\lambda)$
$F_1(\lambda)$
$f_1(\lambda)$
TIP CHORD / ROOT CHORD = λ
VALUE OF $f_5(\lambda)$ WHERE $\frac{A_5}{c_0} = f_5(\lambda)\alpha - F_5(\lambda)\phi$
VALUE OF $F_5(\lambda)$
$f_5(\lambda)$
$F_5(\lambda)$
TIP CHORD / CENTRE CHORD = λ

Fig.

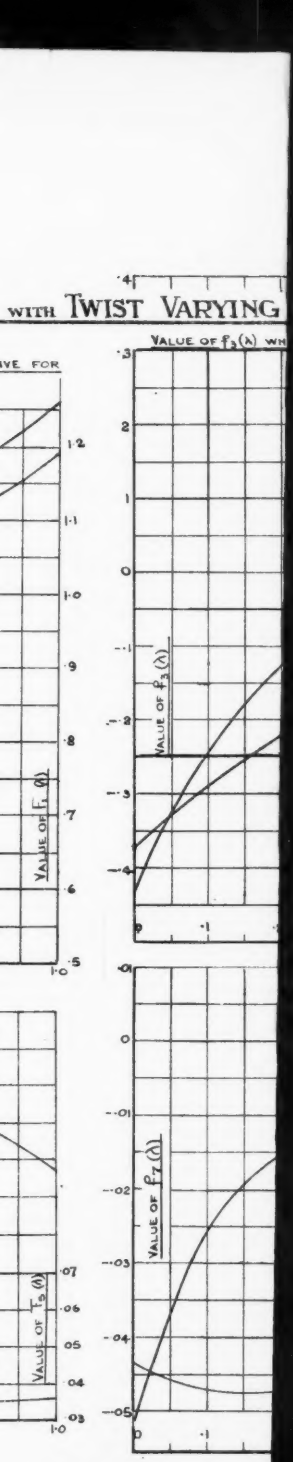

WITH TWIST VARYING
VALUE OF $F_3(\lambda)$ WH
VALUE OF $F_3(\lambda)$
VALUE OF $F_7(\lambda)$
VALUE OF $F_5(\theta)$
VALUE OF $F_5(\theta)$

Fig. 11.

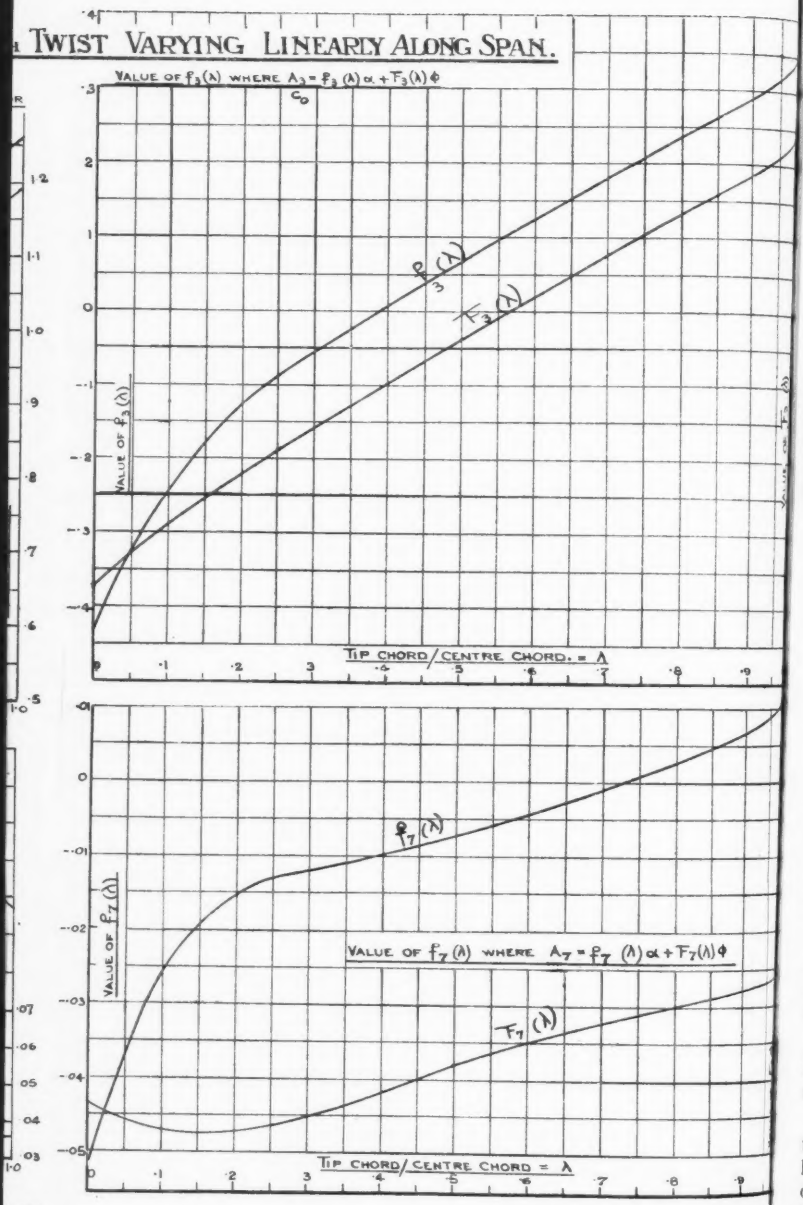

TWIST VARYING LINEARLY ALONG SPAN.
VALUE OF $f_3(\lambda)$ WHERE $A_3 = p_3(\lambda)\alpha + F_3(\lambda)\phi$
C_D
$p_3(\lambda)$
$F_3(\lambda)$
VALUE OF $f_3(\lambda)$
TIP CHORD/CENTRE CHORD. = λ
$p_7(\lambda)$
VALUE OF $f_7(\lambda)$ WHERE $A_7 = p_7(\lambda)\alpha + F_7(\lambda)\phi$
$F_7(\lambda)$
VALUE OF $f_7(\lambda)$
TIP CHORD/CENTRE CHORD = λ

Fig. 11.

to be taken into account. An element of uncertainty is introduced by the additional stiffness of ribs, fabric, etc. This is discussed further below.

3. Even after the determination of moments the finding of the greatest fibre stress in the spar does not follow immediately; both horizontal and vertical moments are involved, and the greatest fibre stress does not necessarily occur at the highest point of the spar.

Fig. X. shows the vertical and horizontal bending moments for a typical staggered spar design. The upper curves are the usual familiar bending moment diagrams for a single bay wing. The lower curves (drawn to the same scale) show the horizontal bending moment diagrams which would not exist at all in a normal spar. The triangles are due to the effect of horizontal constraint mentioned above. The diagrams refer to a top rear spar. The shaded areas in the diagram correspond to convexity upwards and backwards respectively. For example, the outer tip of the spars tends to move upwards and backwards under the vertical air load. The backward movement is restrained by the drag bracing in the overhang, thus producing the peak in the horizontal B.M. curve. The small parabolæ in the lower diagram represent the bending moments due to the lateral drag loading produced by the air and mutual action between the spars. They are clearly negligibly small compared with the induced horizontal bending moments due to the lift load. The stagger angle of this spar had only the quite moderate value of 18°.

If the lateral stiffness of the wing could be assumed very large, these effects could be ignored and the spar treated as though the lift plane of bending were actually a principal plane of the spar. The spars would then reduce to the ordinary case and much labour could be saved. The load factors in the spars for which the diagrams are drawn have been calculated both when the effects of stagger are included and when they are ignored. The results are shown diagrammatically at the top of Fig. X.

The points connected by the full line give the load factors when stagger effects are ignored. The points connected by the dotted line are the load factors when stagger effects are included. Except at one point the inclusion of stagger reduces the load factor, and one is reluctantly forced to the conclusion that it is not safe to ignore it. In the middle of the bay the load factor is reduced from 5·3 to 2·4 so that omission of the stagger effects would be optimistic by more than 100 per cent.

It must be admitted that the true state of affairs is probably intermediate, as the lateral stiffness of the wing as a whole is undoubtedly greater than the sum of the lateral stiffness of the two spars. Until quantitative evidence is available, however, it is safer to ignore this effect.

To illustrate the laborious nature of these calculations I summarise below the separate operations in strength calculations on the staggered spars of a two-bay biplane with a drag bay in the overhang and two drag bays in each lift bay, the spar sections differing in the two lift bays.

(1) Calculation of horizontal spar loadings, involving both moments of inertia and the product of inertia of both spars. These are calculated by determining the moments of inertia of the spar about three axes.

(2) An extension of the normal "three-moment" theorem is applied over the drag bays. This "three-moment" equation gives a relation between three horizontal moments and three vertical moments for each spar, and contains deflection terms for the points of drag support. The further equations necessary for the solution are obtained from the condition that the vertical reactions at the drag nodes are zero. Thus for a two-bay biplane with pin-joint at centre section strut *eleven* simultaneous equations would have to be solved.

The above replaces the usual three-moment equations for an unstaggered spar in which the unknowns would be two only.

(3) At each point where the factor is required, moments of inertia about three axes have to be obtained. Substitution of the horizontal and vertical bending moments in a formula gives the maximum direct stress.

(4) The position of the maximum shear stress at any section is not easily determined so that several critical planes of shear have to be examined.

I think you will agree with me that the lot of one who sets out to stress a staggered spar is, like that of Gilbert's policeman, not a happy one. The way is hard and the pitfalls are many. It is, I think, open to doubt whether any advantage is to be derived from this type of construction. Though a reduction in fitting weight is possible, it will be accompanied by some increase in weight of the spars and with several attendant technical difficulties and uncertainties.

IV.—Normal Accelerations

The most valuable evidence on actual external loads is derived from accelerometer records, and I have collected in Table II. a summary of published British and American results. The British results will be already familiar and show the greatest acceleration as 4.2 g. in a mock fight between a Bristol Fighter and an S.E.5. The American results, except for the series in Report No. 203, call for no special comment. The records of flight in bumpy weather show accelerations down to —.5 g. due to gusts as mentioned above in the nose-diving case. The series of tests extracted from N.A.C.A. Reports 203 are of some interest. They were carried out with the specific object of ascertaining what were the maximum loads which the pilot could put on. For example, the series of recoveries from dives at steadily increasing air speeds show steadily increasing acceleration. In fact the accelerations are quite closely proportional to the squares of the speeds, a result fully in accordance with preconceived ideas.

This report contains some very interesting notes on the pilot's physical experiences during these tests. For example, he says of the spin in which an acceleration of 5.5 g. is reached: "After steady conditions were reached the pilot gradually began to lose his sight, and for a short time everything went black except for an occasional shooting star, similar to those seen when one is struck on the jaw. The pilot appeared to retain all his faculties except sight, and no difficulty was experienced in righting the airplane. Sight returned almost immediately when the acceleration was decreased to normal by restoring the airplane to a condition of steady level flight. The effect of this manœuvre on the pilot is not particularly uncomfortable. The sensation is that of having a tight band around the forehead and a feeling that the eyeballs are about half an inch too low in their sockets." The acceleration in this manœuvre was maintained for about two seconds.

The question as to whether there is any maximum acceleration which the human body can stand naturally suggests itself as being of interest from a structural design standpoint, for if any such maximum were established, it could be used as a basis for a superior limit to load factors, there being no point in making the aeroplane capable of carrying a greater load than its human contents can stand. The opinion of the American medical authorities as given in this report does not give much hope that such a criterion can be fixed, for they say: "From the results of these tests it is apparent that serious physical disorders do not result from extremely high accelerations of very short duration, but that accelerations of the order of 4.5 g. continued for any length of time result in complete loss of faculties."

TABLE II.

ACCELEROMETER RECORDS.

Reference.	Aircraft.	Manœuvre.	Maximum Acceleration.	Time to reach Maximum Acceleration in seconds.	Air Speed M.P.H.	Maximum rate of change of Acceleration per second.
British R. & M. 409	Bristol Fighter	Recovery from Spin ...	2.1 *g*	3.1	105	.6 *g*
		Loop	3.9	3.1	128	1.7
		Side Slip	2.3	2.0	—	.9
		Roll	2.7	3.2	84	.6
	S.E.5	Mock Fight	4.1	1.7	—	2.5
American N.A.C.A. Report No. 99	J.N.—4H.	Recovery from Dive ...	3.5 *	.85 (approx)	80	3.0
		,, ,, ...	2.8 *	ditto	70	2.1
		,, ,, ...	2.0 *	ditto	60	1.2
		,, ,, ...	1.5 *	ditto	50	.5
American N.A.C.A. Report No. 163	S.E.5.A.	Loop	3.8	2.8	102	2.0
		R.H. Roll	2.9	1.1	90	3.5
		R.H. Spin	3.2	1.3	95	2.1
		"Wing Over" ...	2.6	1.8	91	1.5
		Side Slip	1.2	1.1	88	.5
American N.A.C.A. Report No. 155	J.N.—4H.	Loop	3.6	3.2	80	.9
		Recovery from Dive ...	2.0	2.0	75	2.2
		R.H. Spin	3.0	2.2	74	.8
		R.H. Barrel Roll ...	3.8	1.2	90	3.0
American N.A.C.A. Report No. 203	Fokker P.W.7	Loop	6.1	—	160	—
		Barrel Roll	7.2	—	160	—
		Spiral, Engine On ...	5.5	—	140	—
		Immelman Turn ...	4.4	—	150	—
		Inverted Flight ...	1.3	—	—	—
		Vertical Bank... ...	5.7	—	150	—
		Spin, Engine Off ...	2.6	—	—	—
		Spin, Engine On ...	2.3	—	—	—
	D.H.4B.	Normal Flight in Mountainous Country	2	—	—	—
		Normal Flight in Bumpy Weather ...	2.2 to .5	—	—	—
	Fokker P.W.7	Recovery from Dive ...	1.3 *	—	66.3	—
		,, ,, ...	1.6 *	—	76	—
		,, ,, ...	2.1 *	—	85.6	—
		,, ,, ...	2.7 *	—	95.3	—
		,, ,, ...	3.3 *	—	105.0	—
		,, ,, ...	3.9 *	—	114.5	—
		,, ,, ...	4.6 *	—	124.6	—
		,, ,, ...	5.3 *	—	133.6	—
		,, ,, ...	6.1 *	—	143.3	—
		,, ,, ...	6.4 *	—	153.0	—
		,, ,, ...	7.8 *	—	162.5	—
Journal of the I.E.E., April, 1924	Passenger Lift		1.4	1.4		7.5

*These Accelerations correspond to the fastest "Pull-Out" the Pilot is capable of performing.

I have included in the table columns showing the time to reach maximum acceleration and the maximum rate of change of acceleration as well as it could be deduced from the records. This is a rough measure of the violence with which the pilot has manœuvred his craft, and is, I understand, believed to have some bearing on his physical sensations. The highest British figure is 2.5 g. per second in the mock fight mentioned above, and the highest American figure 3.5 g. per second in a roll. On the whole the American times to reach maximum acceleration are shorter and the rate of change of acceleration higher than the British.

For comparative purposes I have included the results of measurements on the acceleration in a passenger lift given in the Proceedings of the Institution of Electrical Engineers for April, 1924. Though the actual acceleration reached is small, only 1.4 g., yet the rate of change of acceleration is very large, 7.5 g. per second, far higher than in any aeroplane results.

I have added a column showing, wherever I could find it recorded, the air speed at the time of the manœuvre, but this is usually only the pilot's reading of the air speed indicator before he begins the manœuvre and so is not a true indication of the actual air speed at the time of the maximum acceleration. Only in one series (British R. & M. 409) was a continuous record of air speed made. The advantage of knowing the air speed is that if the weight and height are also known, an approximation can be made to the highest lift coefficient reached.

This is an important matter from the strength point of view and it seems to me highly desirable that air speed and all other relevant details should be recorded simultaneously with the acceleration. With knowledge of the lift coefficient we can fix with fair accuracy the position of the centre of pressure and other aerodynamic conditions, and so calculate the actual loads arising. Accumulated data of this kind are essential for improvement in our methods of fixing wing and strength requirements.

Conclusion

I have only been able to indicate a few aspects of a question which bristles with problems both general and specific. As they arise, *ad hoc* solutions are found to these, but the aeroplane will not reach its highest efficiency until a rational system of aircraft structural design has been evolved.

In conclusion, I should like to record my most cordial thanks to my colleague at the R.A.E., Mr. K. T. Spencer, for his invaluable help in the preparation of this paper.

Appendix I.

Characteristics of Tapered Wings on Vortex Theory

It is shown in R. & M. 824 ("A Method of Calculating the Characteristics of a Tapered Wing," by H. Glauert) that the load distribution curve for a tapered wing can be defined by the series:—

$$w \text{ varies as } A_1 \sin\theta + A_3 \sin 3\theta + A_5 \sin 5\theta + A_7 \sin 7\theta + \ldots \quad . \quad (1)$$

where $\cos\theta = x/s$

x = distance from wing root.
s = semi-span.
w = load per unit length of span.

and A_1, A_3, A_5, A_7, etc., are constants depending upon the geometry of the wing

and aerodynamic characteristics of the separate aerofoil sections. These constants are found by writing down equations of the form

$$\Sigma \sin n\theta \,(\sin\theta + nac/4s)\, A_n = acw \sin\theta \quad . \quad . \quad . \quad (2)$$

for a number of points along the wing sufficient to determine the number of constants A_n taken. In equation (2):—

a = slope of lift coefficient against angle of incidence curve (in radians) for particular aerofoils in two-dimensional flow (infinite aspect ratio).
c = chord of wing.
α = incidence at point (radians).

It is further shown (*loc. cit.*) that the total lift on one half wing is given by

$$L = (\pi s/4)\, \rho V^2 A_1,$$

where L is the lift and V the forward speed and ρ the air density. It is found that four terms of (1) are enough to give a reasonably accurate curve so that four simultaneous equations of the type (2) have to be written down for four selected points to find A_1, A_3, A_5 and A_7.

Extensions of above Equations to Shear Force and Bending Moment at Any Point

Where the values of the constants A_1, etc., are known, the shear force and bending moment can be found analytically if desired as follows. By successive integration of equation (1) we obtain

$$S \text{ varies as } s\,[A_1\theta/2 + \{(A_3 - A_1)/4\}\sin 2\theta + \{(A_5 - A_3)/8\}\sin 4\theta + \{(A_7 - A_5)/12\}\sin 6\theta - (A_7/16)\sin 8\theta] \quad . \quad . \quad . \quad (3)$$

S being the shear (due to air load) at the point denoted by θ.

At the root where $\theta = \pi/2$

$$S_0 \text{ varies as } (\pi s/4)\, A_1,$$

but

$$S_0 = L = (\pi s/4)\, \rho V^2 A_1$$

so that if the R.H.S. of (3) be multiplied by ρV^2 the "varies as" can be replaced by "equals."

Similarly, for bending moment B,

$$B/\rho V^2 = s^2\,[-\tfrac{1}{2}A_1\theta\cos\theta + \{(3A_1 + A_3)/8\}\sin\theta + \{(2A_1 - 3A_3 + A_5)/48\}\sin 3\theta + \{(3A_3 - 5A_5 + 2A_7)/240\}\sin 5\theta + \{(4A_5 - 7A_7)/672\}\sin 7\theta + (A_7/288)\sin 9\theta] \quad . \quad . \quad . \quad . \quad . \quad (4)$$

At the root $\theta = \pi/2$

$$B_0/\rho V^2 = s^2\,(A_1/3 + A_3/5 - A_5/21 + A_7/45)$$

The distance of the resultant centre of pressure from the root can hence be readily deduced.

Straight Tapered Wings

For a straight tapered wing of given ratio λ (tip chord/root chord), the chord at any given fractional distance from the root will depend upon the aspect ratio. For the generalised curves given in this paper, an aspect ratio 6 has been taken. In addition it has been necessary to assume a value for "a" (the slope of the lift coefficient curve for infinite aspect ratio); "a" has been taken equal to π for all sections.

In a straight tapered wing it can easily be shown that for a given value of λ and for a given type of twist the values of A_1, A_3, etc., are linear functions of root incidence. Curves for finding A_1, A_3, A_5 and A_7 are shown in Fig. 11.

Position of Centre of Pressure Along Chord in a Straight Tapered Wing

It may be assumed with fair accuracy that for angles below the stall the pitching moment on an aerofoil section is a linear function of the lift coefficient. This fact may be used to deduce simple expressions for the pitching moment on a straight tapered wing. Assume that the coefficient of pitching moment referred to the line joining the intersection of the leading and trailing edges (the datum line in Fig. 3) is given by

$$k_M = P + Qk_L$$

Then the pitching moment for one half wing is given by

$$M/\rho V^2 = \int_0^s k_M c^2 dx = P \int_0^s c^2 dx + Q \int_0^s wc\,dx$$

Writing

$$\gamma = 1 - \lambda$$

it follows that

$$M/\rho V^2 = Pc_0^2 s\,(1 - \gamma + \tfrac{1}{3}\gamma^2) + Qc_0 s\,(\pi/4)\,A_1 - Qc_0 s\gamma\,(A_1/3 + A_3/5 - A_5/21 + A_7/45)$$

The distance of the resultant centre of pressure of the resultant from the datum line follows immediately.

APPENDIX II.

Deflection of Cantilever Beams of Uniform Strength

Let h = semi-depth of beam at a distance x from root.
h_0 and h' be semi-depth at root and tip respectively.
s = distance from root to tip.

Write

$z = x/s$.
$h/h_0 = p$.
f = maximum fibre stress (assumed constant throughout).

The deflection of the beam is referred to axes such that the deflection and slope are zero at the root.

I.—General Case

We have at any point distant x from the root bending moment $= EId^2y/dx^2 = fI/h$.

$$\therefore\ d^2y/dx^2 = fI/Eh$$

Changing x to z and h to p this becomes

$$d^2y/dz^2 = (fs^2/Eh_0)\ (1/p)$$

Writing

$$fs^2/Eh_0 = C$$

$$dy/dz = C\int_0^z dz/p$$

$$y = C\int_0^z \int_0^z (dz)^2/p$$

The tip deflection Δ is given by

$$\Delta = (C/2)\,m$$

where

$$m = 2\int_0^1 \int_0^1 (dz)^2/p$$

"m" is clearly a purely geometrical function of the spar, and is shown plotted for the following cases in Fig. 9.

II.—Beam of Constant Depth

For this case

$$p = 1$$
$$\therefore\ m = 1$$
$$\Delta = C/2$$

III.—Straight Tapered Beam

For this case

$$p = 1 + (p' - 1)\, z$$

p' being the value of p at the tip.

Hence

$$m = 2\,(p' \log_e p' + 1 - p')/(1 - p')^2$$

IV.—Beam with Elliptic Taper

For this case it is assumed that

$$p^2 = 1 - (1 - p'^2)\, z^2$$

and it follows that

$$m = 2\,(\sqrt{1 - p'^2}\, \sin^{-1} \sqrt{1 - p'^2} + p' - 1)/(1 - p'^2)$$

V.—Beam with Parabolic Taper Convex Outwards

The apex of the parabola is taken at the root and the equation assumed is

$$p = 1 - (1 - p')\, z^2$$

It follows that

$$m = (\log_e p')/(1 - p') + \{1/\sqrt{(1 - p')}\} \log_e (1 + \sqrt{1 - p'})/(1 - \sqrt{1 - p'})$$

VI.—Beam with Parabolic Taper Concave Outwards

The equation assumed is

$$p = p' + (1 - p')\, (1 - z)^2$$

It follows that

$$m = (\log_e p')/(p' - 1)$$

VII.—Beam of Unknown Mathematical Form, but of Known Height at all Points

This case may be dealt with either by graphical integration or by the method described by Dr. A. A. Griffiths in R. & M. 545 (The Approximate Solution of Linear Differential Equations), and may be made to give results of any required degree of accuracy, according to the number of points taken. The method is given below for four points and can readily be extended to a larger number.

Writing

$$q = 1/p = h_0/h$$

the equation to be solved is

$$d^2y/dz^2 = Cq \qquad \ldots\ldots \quad (1)$$

with the conditions that when

$$\left.\begin{matrix} z = 0 & y = 0 \\ & dy/dz = 0 \end{matrix}\right\} \qquad \ldots\ldots \quad (2)$$

Assume

$$y = C\,(a_0 + a_1 z + a_2 z^2 + a_3 z^3 + a_4 z^4 + a_5 z^5).$$

It follows from (2) that

$$a_0 = a_1 = 0.$$

Hence

$$Cq = d^2y/dz^2 = C\,(2a_2 + 6a_3z + 12a_4z^2 + 20a_5\,z^3).$$

Since at the root where $z=0$, $q=1$, it follows that $a_2=\frac{1}{2}$, and

$$q = 1 + 6a_3z + 12a_4z^2 + 20a_5z^3 \quad . \quad . \quad . \quad . \quad (3)$$

By selecting three points along the span (in addition to the root point already taken) and inserting appropriate values for q and z, three simultaneous equations to determine a_3, a_4 and a_5 are obtained.

The tip deflection is given by

$$\Delta = C\,(a_2 + a_3 + a_4 + a_5).$$

If we take

$q = q'$ when $z = 1$ (tip)
$q = q_1$ when $z = \frac{1}{2}$
$q = q_2$ when $z = \frac{1}{4}$

Then

$$\Delta = (C/90)\,(9 + 2q' + 18q_1 + 16q_2).$$

Discussion

Sir Sefton Brancker: Before I hand the Lecturer over to the mercies of the experts there are one or two points I should like to make. I often say that there are frequent occasions when science follows laboriously in the track of practical achievement. It sometimes sets out to prove that the man who did the thing a year ago did do it and did it right. This question of acceleration is a case of the reverse process. A short time ago I was talking to a very responsible and experienced pilot about the Schneider Cup Race, and suggested that the crash in which Biard was concerned was due to the increase of "g" and that the high accelerations had had the effect of making him partially lose consciousness and so get out of control. The expert pilot said it was nonsense; in his experience high accelerations of this class had no effect on the pilot whatever. A few minutes after our conversation I took up and began to read Mr. Howard's draft paper and found his comments on the measure of acceleration which pilots could stand, and the effect which the rate of change had upon them. I had much pleasure in sending my pilot friend a cutting from the paper.

With regard to the Schneider Cup race, I believe that two of the American pilots were the scientific test pilots from McCook Field. They were the people who went up with parachutes to find out by diving steeply, and if necessary breaking their machines, what these acceleration forces really were; the table given by Mr. Howard was the result of their efforts. The race has shown us that this question of acceleration is of great importance for pilots as well as for machines. I hear that the Americans had specially trained themselves to stand the strain, even going to the length of doing special exercises to develop the muscles of the stomach.

I should like to ask the lecturer how far he is confident that the airworthiness people can deal with metal construction. You all know that the experts in metal construction think they can save a considerable amount of weight as compared to wood, and that is one of the most important lines of progress at the present day. How far the stress merchants think they really know the ins and outs of metal construction I do not know, and any light the Lecturer could give us on this point would be of interest.

The Lecturer has told us that a great deal of work has been done on the tapered monoplane wing. Theoretically, yes; but not in practice; here I think that we are behind other countries. The monoplane of this type appears to me

to offer considerable advantages from the commercial point of view, but our designers have not had much success in its development so far.

The differences in the results arrived at when using the Prandtl and "Strip" theory are a little alarming. With the one a wing may be calculated to be too weak, and with the other too strong. I should like to hear more about this question.

Mr. MANNING: With regard to tapered wings, one point which the Lecturer did not mention is the question of fixing such a wing to the fuselage. The rigidity of the fixing will have a considerable effect on the rigidity of the wing. I refer, principally, to the torque rigidity of the fuselage between the spars; a small deflection here means a much increased variation of angle between the two wing tips.

Another point is the question of distortion of the wing caused by the effect of operating the ailerons.

Another point of considerable importance, as pointed out by the Chairman, is the torque vibration or flutter of the wing tips on wings of this type. Many wings appear not to be subject to flutter. Certain foreign built monoplanes appear to be free from it. A designer takes a considerable responsibility if he designs a wing without satisfying himself that this trouble will not arise, and at present we have no theoretical information on the subject. The matter is extremely complicated.

I am also interested in the question of the effect of accelerations in flight on the pilot. The most satisfactory solution would be found by testing a few pilots to destruction, but perhaps they would not receive this suggestion with enthusiasm. I notice that the Lecturer supports the point of view that some people hold, that the rate of change of acceleration is the important factor. I should imagine that that factor was not very important. If I were to jump from a height of 7 or 8 feet the rate of change of deceleration would probably be very high when I landed, but I do not suppose I should be much affected by it. I think that $g \times$ time is the important factor.

Also with regard to the particular instance to which he drew attention where an American pilot happened to stand 5.5 g the question arises as to whether that man was exceptional. A pilot might increase his power of resistance by steady practice. One might imagine that the effect on a short man would be less than that on a tall one.

I should like to thank the Lecturer for his paper, which is a valuable addition to the Proceedings of the Society.

Major LOW: The paper read to them that evening was no doubt in the first written by a specialist for other specialists, but within the limits set by the Author, the speaker felt he must praise it highly for the lucid manner in which the most recent developments were presented.

The illustrations showed the non-specialist how the "factor of ignorance" had hitherto cloaked our lack of knowledge and how half its value was required to cover a faulty theory.

The Chairman, however, need have no anxiety as to flying in aeroplanes designed on the old lines, for in aviation, as in other branches of engineering, when numerous aeroplanes had been built from the same design and flown under all sorts of conditions, any weak point in the design was in course of time demonstrated effectively—sometimes tragically. Thus, with an established design, one might say with a high degree of confidence, excluding unforeseen conditions, that it was strong enough for the job.

It might be asked fairly, what then was the use of a more accurate theory.

Its use was that it not only confirmed the load factors got out under the less accurate theory, it pointed out those parts of the structure which were unnecessarily heavy and which could be lightened with safety.

Some constructors in the past, and he feared some in the present, had seemed to underestimate the value of having a sound physical theory underlying their methods of design. It was quite true that no mathematical physicist working in the study, aloof from the actual building and running of aeroplanes, could possibly foresee all the considerations that entered into a design which was to prove successful in the field.

On the other hand, they would be blind indeed if they did not see that constant interaction between the physicist and the constructor, with an able corps of aeroplane designers as go-betweens, had contributed a substantial part of the detailed improvements in design, the sum of which constituted the difference between the pioneer aeroplanes and the present day instruments of civil and military aviation.

In conclusion, he congratulated the Lecturer again on the high technical standard of his paper and on his evident mastery of the latest developments of the physical theory of flight.

Mr. PRITCHARD: I should like to congratulate the Author on his paper. It takes a considerable amount of courage for any stress merchant to come before an audience largely made up of engineers. I have been a stress merchant myself and, unfortunately, was rather keen on the superiority of mathematics over general engineering. I got rather badly kicked by engineers as a result.

I should like to take the opportunity for pressing for a liaison between engineers and mathematicians, because I find that one of the great troubles of the mathematician is that he does not get proper data from engineers; not because the engineer is not willing to give him that data, but because he assumes that the mathematician knows more than he does of their practical limits. I remember we asked a mathematician to get us out the best shape for a strut under certain conditions. He was left alone, and after three days' thought he said that the strut would have to be infinitely long and thin. On looking through his figures it was found that he had been calculating on wood cut to an accuracy of six places of decimals. When told that the necessary wood could not be prepared under, say, 1/16th of an inch, he produced the desired shape at once. I think if there were some liaison between the two, much better results would be obtained from the mathematician.

One point I should like to raise is the question of staggered spars. Mr. Howard said that it is open to doubt whether any advantage is to be derived from this type of construction. It seems to me that there is a considerable amount of advantage to be obtained from staggered spars from the aerodynamical point of view. The trouble really is that it is much more difficult to calculate the stresses on a staggered spar than on the other type. In actual practice there are many advantages, as economy of fitting and so on.

Mr. BRAMSON: I am a mere visitor, but I should be very glad to contribute what I can to this discussion. One point which the Lecturer was about to deal with but did not actually come to was the question of wing vibration, which Mr. Manning has already raised. I happened to read in the special edition of a German aeronautical paper on the occasion of the Prandtl anniversary an article dealing with the possibility of the wing becoming elastically unstable, due to an accidental twist. Assuming that a wing is flying normally at any particular incidence, and the incidence is increased so that the centre of pressure moves forward, causing a change of twisting moment. That will further increase the incidence and make the centre of pressure move still further forward. That forward movement causes again an increase of twisting moment, and so on.

If the rate at which this externally applied twist increases is greater that the rate of increase of the internal moment of the wing structure opposing twist, you have an unstable wing which will break. I want to know whether in the Lecturer's opinion this is the explanation of a wing flutter. There are other cases in which the wing might be unstable apart from the normal oscillation about the longitudinal axis, and resonance with engine harmonics might give rise both to longitudinal and torsional oscillations of the wing, with risk of fracture. It would be interesting to know whether that, in the Lecturer's opinion, might give rise to unexplained breakages, or whether one might consider one is safe with normal wing spars.

Acceleration.—We have inside us various organs of different weights, kept in place by definite ligaments. I daresay that from the data already known about these, definite figures could be worked out for a limit of what a man could stand.

General Brancker referred to Doolittle's exploit. I have heard rumours, I do not know how true they are, that there is a theory for making fast turns when racing. A good deal was written in the flying papers before the race, and a good many people said the pilot would have to throttle down before making his turn. In a race you must climb just before you make the turn and utilise the extra height for the purpose of adding to your total available power, thereupon steadily losing height in flying down to your next turn. I have heard that that is what Doolittle did do.

I should like to add my thanks to the Lecturer for his paper.

Mr. W. D. Douglas: I should like to add my thanks to the Lecturer. I am very interested in all parts of his paper, but one point I should like to amplify is the endeavour that has been made to find out what a pilot can stand in the way of accelerations. Some time ago I tried to approach this from the general aspect and looked round for records of what accelerations had safely been withstood. People had been whirled round at the end of a rope and had thus been subjected to considerable accelerations for definite periods. Dr. Thurston was, I believe, thus treated to the point of losing consciousness for some time.

In sport one finds certain cases where the body is subjected to considerable accelerations or decelerations. We read of men diving vertically from great heights, often into a few feet of water. They must experience big acceleration forces while changing direction. Naturally, we may be pretty certain that the water was sometimes considerably deeper than claimed, as the account tends to minimise the depth. These records do not help us very much as we have no accurate record of the under-water path. I believe that a cinematograph company took under-water photographs of the results of high dives, but I have not yet seen them.

It was thought that saving of life in fire by means of blanket-jumps might furnish some records of decelerations, but this is a method that is going out of use, and records of the results of actual jumps are difficult to obtain. Presumably the fire brigade are too busy with the more important work of saving life, or putting out fire, to spend time making non-essential records. At one fire station they had some figures with regard to test jumps, but the limiting height for these apparently depended on whether the jumper had boots on or not; if he had boots on he could land fairly well from 20 feet, without boots it appeared that he was likely to sprain his ankles. From these and similar sources it may, however, be possible to compile some data on the effect of accelerations acting for definite times. At the same time there is a very widespread feeling that rate of change is important from the comfort point of view. American high-speed lift designers base their results on experience of this factor. They find it is the rate of change of acceleration that troubles passengers. If the rate of change is kept down discomfort is automatically eliminated.

Discussing this matter with physiologists revealed fresh difficulties. They could not say definitely that any one part of the system is the limiting factor—generally it is the liver or spleen that give trouble as they are heavy organs, but it will naturally depend on the position in which the pilot is sitting and the directions in which the acceleration takes place. It is evident that the time factor must come in. An acceleration that takes place for a very short time may, under certain conditions, be harmless although of high value.

Testing personnel to destruction is a very natural suggestion which has often been made. There seemed to be no difficulty when this cropped up some time ago, in compiling a private list of proposed experimental subjects. On the other hand, several pilots were seriously prepared to submit themselves for much more severe tests than had yet been made. Before such tests can be started officially, however, it is necessary to obtain medical approval, and this would be difficult since it evidently would not be easy to say at what stage such tests become dangerous. I believe one pilot carried out some unofficial dropping tests, bringing himself to rest by a cable and spring balance. Such crude tests, unfortunately, do not give much information of the form required.

It is probably worth while trying to find the formula for the physiological resistance of the average pilot, because it might set a limit to the useful strength of high-speed aircraft.

Mr. Oswald: I should like to ask a question in regard to the results obtained by the Strip and the Prandtl theory for tapered wings. I burn my boats immediately by admitting that those obtained by the Prandtl theory are more accurate.

If one assumes that the load is a simple function of the chord, as is implied by the Strip theory, then the ordinates of the standard load curve are simply increased in height in proportion to the chord at the particular abscissa and results can be obtained for bending moments, etc., very quickly.

From the imperfect study of the curves which one is able to make during the lecture, I came to the conclusion that for tip chord to root chord ratios between .34 and .5 the two theories gave results which either coincide or that the Strip theory gave slightly heavier loads. Thus the design on the latter bases would be safe.

In practice, the tip chord to root chord ratios lie between .34 and .5, triangular wings being ruled out. Further practical considerations call for spars stronger at the tips than is theoretically necessary, thus the increase in spar weight by using the heavier loads of the Strip theory would probably be negligible.

Therefore, from the point of view of a practical application of the results the question arises, is the greater accuracy obtained by the Prandtl results as against those of the Strip theory, such that the apparently longer time and therefore greater cost for calculations by the former is justified. Probably the Lecturer has had calculations carried out by both methods for a set of wings and can say definitely whether more calculation time is necessary for the one or the other.

I should like to thank the Lecturer for a most excellent paper.

Mr. G. L. Brazier (*communicated*): Some general considerations lead us to expect an important advantage for staggered spars. In the ordinary wing the movement of the centre of pressure between the two spars requires that the sum of the strengths of the two spars must be considerably greater than the total load they are called upon to carry. And there is a loss of weight efficiency. It is clear that any constraint opposing a differential strain of the two spars will reduce this margin of surplus strength. Of possible forms of such a constraint the staggering of the spars is a practically ideal example. Further, the method not only introduces the differential constraint but takes advantage of the extra rigidity of the drag truss when this has a greater number of bays than the lift

truss. And this advantage is obtained from a truss which is entirely inside the aerofoil and can introduce no aerodynamic resistance. It is interesting also that the maximum support will be obtained from the differential constraint in the nose-diving case when the loads on the spars are in opposite senses.

These considerations do not appear to be supported by the low factors given by Mr. Howard. Mr. Howard's paper is likely to result in delaying the development of a device that may ultimately prove valuable to the aircraft designer. I may, therefore, perhaps be permitted to add that, for reasons into which this is not a suitable opportunity to go, I do not regard these factors as a disproof of the existence of the expected advantages.

Mr. HOWARD, in his reply, said: The Chairman asked whether all the passengers would really be in a heap in the nose in a terminal dive; this would happen as the aircraft is not falling freely, but at uniform speed. He also asked how the Airworthiness Department deal with metal construction. This has certainly raised some difficult problems from the structural strength point of view. Thrust, however, can always be made to strength test in order to find the stress a particular design will stand.

I should like to second Major Low's remarks on "Strip" versus "Prandtl" theory and set the Chairman's mind at rest on the lines he indicated. I agree with Major Low that "distribution" is preferable to "grading" and will make the necessary changes.

Mr. Manning mentioned the effect of fuselage attachment on tip deflection and also a number of other points in monoplane design. I have not attempted in the present paper a comprehensive treatment of cantilever wing deflections, but have discussed only the effect of the shape of the spar.

One or two speakers mentioned the subject of wing vibrations. I deliberately refrained from discussing this point as very little has so far been published on it. It is a complicated problem, both mathematically and aerodynamically, and there is very little information available at the present time.

Several speakers mentioned the subject of how far the rate of change of acceleration affects physical sensations. Mr. Douglas summed the present position up for us fairly completely. My object in tabulating the rates of change of acceleration was to obtain some quantitative data on the point. I have no cut-and-dried suggestions as to how it should be used.

Mr. Pritchard thinks we ought to build staggered spars. I do not, on the grounds that it is by no means certain that any weight will be saved, and it is quite certain that many technical difficulties and uncertainties will arise. Much time and labour is consumed in solving the problem and at the end there is doubt about the accuracy of the results.

Mr. Oswald queried my suggestion that we can abandon the Strip theory and asked if we have compared the results on actual wings. We have not applied the Prandtl theory to very many wings so far because the new methods have only just been completed, but I think that with a little use they should not prove any more laborious than the Strip theory, and if it is as easy to be right as to be wrong, why not be right?

In conclusion, I should like to thank the Society most cordially for their very kind reception of my paper.

Reply to Mr. Brazier's written contribution to discussion.

There is no doubt that staggering of spars has the general effects described by Mr. Brazier, but it remains to be proved that the result is to give less weight for a given strength. The balance of evidence at the moment is distinctly in the opposite direction, as indicated in the paper. It might be observed that a mode of constraint opposing differential deflection of the two spars is liable to

cause twisting on the spars themselves. This type of loading is one to which the ordinary wing spar is particularly badly adapted.

Sir SEFTON BRANCKER, in passing a vote of thanks to the Lecturer, said: We got away rather in the discussion from the construction of the aeroplane to the internal fittings of the human body. Our Honorary Secretary tells me that tests have been carried out when hanging men to find out the best way of doing it. An eight stone man gets a six-foot drop; a ten stone man needs a drop of 5ft. 6in., and a twelve-foot drop will pull anyone's head off. The question of how much a pilot can stand is really an extremely important question; but I think that we have arrived at the point at which we must hand him over to the doctors. Towards the end of January Major Buchanan will, I hope, lecture to the Society on the Schneider Cup Race. I hope that some medical experts will be present and will give us their views.

Mr. Pritchard mentioned the question of drawing the engineer and mathematician together. The best means of doing this would be to persuade some more mathematicians to join the Society.

You will all join with me in congratulating the Lecturer on his paper. I would like to assure him that because staggered spars involve a considerable amount of time spent on calculation it is no reason for abandoning staggered spars.

A very important branch of research is the study of wing vibration. There have been some mysterious cases of this lately. This is a subject in which there is a considerable blank spot in our knowledge.

The Lecturer and the other members of the Airworthiness Department are going to have plenty more opportunities of thinking when they have to tackle the calculations for the autogiros which are shortly to be built. We all wish him luck in his future career and thank him very much for his excellent paper.

RESEARCH PROBLEMS IN AIRSHIP DEVELOPMENT

BY MAJOR G. HERBERT SCOTT, C.B.E.

Lecture before the Scottish Branch of the Royal Aeronautical Society, October 19th, 1925.

1. At various times during the last three or four years I have read lectures on airships which represent the views of myself and others interested in Airship Development, which endeavoured, while putting forward the great possibilities of the airship for commercial and service purposes, to emphasise that before these possibilities can become realities a large amount of experiment and research was necessary. In my paper this evening I intend discussing some of these problems, and showing how the Air Ministry Airship Development Programme proposes to tackle these problems.

The present Air Ministry Programme consists of building two 5,000,000 cu. ft. airships, one of which will be constructed at the Royal Airship Works, Cardington, and the other is being built on contract by the Airship Guarantee Company, Limited. This scheme is somewhat similar to that adopted by the Admiralty when considering the building of Naval Craft, some being built in Naval Dockyards, and the others in private yards.

The trials of these two airships will be carried out by the Air Ministry, the crew and all operating personnel being supplied by them.

In order to build the 5,000,000 cu. ft. ship at Cardington the existing shed is being heightened and lengthened.

In addition to this ship, the Government are erecting a shed base with mooring mast at Karachi in India, and a mooring mast refuelling base at Ismailia in Egypt. The latter will be ready for operation by the middle of next year, and it is anticipated that the Indian base will be commissioned early in 1927.

The mooring masts that are to be erected at Cardington, Egypt and India are all of a standard type, 200ft. in height, and will be provided with lifts, refuelling and regassing mains, and staircases.

Operational Experiments

The principal operational experiments in the programme are the mooring mast trials in Egypt.

It is proposed to carry out these tests with the R.33 or R36, during the summer of next year, using the new mooring mast base at Ismailia.

I should like to point out that these trials in Egypt are mooring mast trials only, and that the flights to and from Egypt are purely incidental, and in no way constitute a trial in themselves, as given an airship of sufficient range and speed, enough experience has been obtained in the air to make this flight a certainty.

The problem of mooring in tropical and semi-tropical climates, however, presents a number of difficulties on which no data is available in this country, and the object of the experiment is to obtain data on these particular points.

Some of the most important points that need investigation are :—

(1) The behaviour of an airship at a mast under a heavy gradient temperature such as may be expected near the ground in Egypt during certain periods of the day.

(2) The degree of superheat that will be encountered during the hottest part of the day, and the maximum gas temperature that may be expected.

(3) The effect on an airship at the mast of small rotary gusts.

(4) Trying out methods designed to overcome any tendency of an airship to vertical oscillations in the heavy gradient temperature already mentioned.

It will be seen that this data can only be obtained by actual experiment with an airship under the actual conditions expected, and that sooner or later this data must be obtained; also, owing to the unforeseen difficulties that may occur in any experiment of this nature, a certain amount of danger to the airship may exist, until the difficulties, if any, are realised, and successfully overcome. It is for this reason that we are fortunate in being in the position to be able to carry out these tests, with an old and obsolete airship, instead of waiting to carry them out with the new 5,000,000 cu. ft. ship, the R.101.

In addition to these operational experiments a very careful meteorological examination of the route is being carried out by a small section of the meteorological section of the Air Ministry specially detailed for this work.

It is difficult to visualise the enormous amount of work this entails, the first problem being to collect and analyse all existing data on the route; there are bound to be gaps in the data, and methods will have to be devised for filling up these gaps.

In order to fully understand what this means it is necessary to realise the special requirements of the airship, and how in many details these differ from the requirements of other forms of transport.

In the old days of the sailing ship a great deal of information was collected with regard to winds and storms all over the world, and these form a good basis on which to start any examination of a route.

To the sailing ship, however, the surface wind was the only thing that mattered, and the upper winds were only of interest so far as they affected the surface wind.

With any type of aircraft the surface wind is only of interest near or on the landing grounds or bases, the upper winds being the important factor.

Owing to the enormous difference that can exist between the surface wind and the upper wind both in strength and direction it is obvious that a careful examination of these upper winds is necessary.

The forecasting of the weather has also necessitated an examination of the upper winds, so that over areas like the West of Europe sufficient is known about the upper air to meet all the present requirements of the airship.

In fact it is probable that very little, if any additional meteorological services or information will be required as far as wind is concerned, on the first stage of the Indian Route, *i.e.*, England to Egypt.

On the second stage, Egypt to India, there is not the same knowledge of meteorological facilities, and although the Royal Air Force have collected a good deal of data over Mesopotamia, Palestine and Egypt, there are big gaps in the route that need further investigation.

The inauguration of the Imperial Airways service between Egypt and Karachi has necessitated the improvement of the meteorological facilities, and these will be of great value to the Airship route, but it is doubtful whether even with these improved facilities sufficient data will be available.

So far, I have dealt almost entirely with the knowledge of the winds, but there is another, and, to the airship, just as important if not more important factor, and that is temperature.

The data at present available with regard to temperatures of the air at various heights above the ground except in a few special areas is not very full, and I think there is little doubt that further data is essential.

This requirement is particularly an airship one, and it is due to the requirement not having been felt before that accounts to a large extent for the lack of data.

The airship's requirements in this case are of two kinds :—

(1) The temperatures likely to be met with on the route between the heights of say 1,000 to 8,000 feet.

(2) The temperatures and variations in the first 400 or 500 feet over the areas wherein airship bases are situated.

The best method of obtaining data for the first of these requirements is by aeroplane flights at different hours of the day, the aeroplane carrying recording instruments that plot temperature and humidity against barometric height.

A number of flights of this kind have already been made over Egypt, and some most interesting results have been obtained.

There would appear to be general similarity between the results so far obtained, and it is hoped that it may be possible in the future to generalise for these temperatures over fairly large areas.

It is, however, necessary that a good deal more of this type of investigation be carried out over other areas of the route before it can be said that this route is properly charted.

By this I do not mean that this route cannot be flown by airships until it is fully charted, as the airship is herself probably the finest means of collecting the data, but the more data that can be collected and sorted, the more reliable and safe will airship flying become.

It is therefore particularly important in order to produce a steady, sound airship development, that every available means should be used in order to collect information.

With regard to the second temperature requirement, this is of particular importance to an airship moored to a mooring mast, and although it is proposed to send an airship out to Egypt in order to test the effect of the temperature, etc., the airship will only remain in Egypt for a short time; it is therefore important that readings of temperature variation should be taken regularly over a period of at least one year, and these, compared with the behaviour of the airship under recorder conditions, will give a fair indication whether at any time during the day or during any period of the year, danger may be anticipated. It will also define periods when no trouble of any kind may be anticipated; the value of this is obvious.

The method proposed for obtaining this data, is to fix recording instruments at different heights up any high structure in the vicinity of the aerodrome, such as a wireless mast, and to collect daily or at any rate periodic readings over a period of twelve months.

There is in addition a large amount of other data with regard to fog, sandstorms, thunderstorms, etc., to be collected; it will therefore be appreciated what a long task this small section of the Air Ministry Meteorological Section has in hand.

Up to the present I have dealt with only the experiment and research necessary for the operation of an England-India route, but there is in addition a large amount of research required before building a ship of 5,000,000 cu. ft. capacity.

It must be remembered that these two airships, the R.100 and R.101, are over twice the capacity of any previous airship, and this big increase in size is only possible owing to the knowledge that has been obtained by careful investigation of airship design, which was carried out after the loss of R.38.

The results of these investigations showed that there was a number of points that needed full-scale experiment.

The most important of these was the distribution of aerodynamic forces over the hull of an airship in flight. From wind tunnel experiments it was possible to make an estimate of the distribution, but owing to the very big scale difference between the wind tunnel model and the airship it was not known how accurately it was possible to make such an estimate.

It was therefore necessary to carry out some full-scale pressure plotting tests on an existing airship in order to obtain a comparison between the model results and the airship results, and so if possible obtain some methods of applying a scale correction in the same control car, so that all readings were recorded at the same moment.

In order to realise what a difficult job it was to fit up these instruments, one must realise the size of the airship; the pressure points were distributed the full length of the airship, and several miles of rubber tube were employed to connect them up to the various instruments.

When the experiments were carried out, the airship was flown at different speeds, and at different altitudes, both in straight flight and turning flight and records taken at each speed.

These experiments are now complete as far as the flying of the airship is concerned, although the working out of the results will take a considerable time.

Another experiment considered desirable as a result of the investigation into airship design, consists in taking a portion of an airship hull and subjecting it to known forces, the stresses in the individual members of the hull being measured to see how accurately they compare with the calculated stresses.

A portion of R.80, an obsolete ship, is being used for this experiment, three sections of the hull have been turned on end and secured to the floor of the Pulham Shed.

The chief difficulty in this experiment was to devise an instrument which would accurately record the stresses in the various members without in itself affecting the stress or the elasticity of the member.

A suitable instrument, however, has been devised and proved extremely satisfactory in test; a large number of these instruments are now being constructed for the tests.

The above two experiments may be taken as the two biggest of the research experiments that are being carried out under the Airship Development Programme. There are in addition a large number of smaller research experiments in hand, which I do not think would be of great interest to you.

In addition to the research experiments it is the policy of the Air Ministry Design and Construction Staff to test to destruction one of every new portion designed for the R.101. In accordance with this policy a complete section of the hull containing two of the main rings and one gasbag is being built as a test section. This section will be used for test only and will be thoroughly tested out under extreme load conditions before construction on the main hull is commenced.

The R.33 was used for these tests, over 500 pressure points being employed The points consist of a small hole in a flat plate which is attached to the outer cover of the airship; this small hole is connected by a rubber tube to a manometer, the other side of the manometer being connected to a hanging head.

From the reading on the manometer it was thus possible to estimate the pressure at the point where the pressure plate was attached.

It was necessary in order to obtain a complete record that all the 300 pressure points should be read simultaneously; this was done by bringing the

rubber tubing down to special points in the keel of the airship. At each of these points about 30 manometers were grouped into a single instrument, and by switching on an electric light the reading was recorded on sensitised paper; all lights were connected to one switch.

I think I have now given you a general idea of what is involved in a Development Programme of this nature and I believe that you will agree that every possible precaution has been taken to insure success. Unstinted research should be the basis of all aircraft work and I can assure you that all practical experiments deemed necessary will be carried out, without restraint from a financial standpoint, so that no stone is left unturned to achieve success.

There are bound to be minor set backs from time to time, but I am convinced, without being described as an optimist, that an optimistic view can be taken for the future of airship transport.

At the end of the present programme there will be in existence two 150-ton airships, a mooring mast base in Egypt and a shed or repair dock in India at Karachi, also equipped with a mooring mast. How are we then to provide for the continuity of the development of this new form of transport?

There seems little doubt in my mind that the large steamship organisations should be induced to take an interest in the operation of any line operating airships. Transport is a specialised job and no one knows the requirements of the travelling public better than the large shipping organisations of to-day.

It is difficult to judge the attitude of the general public towards air transport, but judging by the returns on the London and Paris air route, there should be no difficulty in obtaining sufficient traffic to fill the ship on every flight in view of the enormous saving in time. One has only to visualise a journey by air to India to appreciate the many advantages airship travel will have over the existing modes of travel. Passengers will embark in England, say at Bedford, and after a journey of two days will land in Egypt for say half a day to allow the ship to refuel; it is probable that the airship would land in the early morning and leave after sunset. Another two to two and a half days on an average should see them landed at India, giving a total journey of about five days. They have only had the trouble of passing through one custom house and no change of craft.

Compare this with the existing mode of travel. One boards a train in London and proceeds to Dover. Here we change on to a Channed steamer and proceed to Calais. Change again to train transport and journey to Marseilles or one of the Italian ports. Another change to steamer and we are at last on board for India. After about 15 days in which to be really seasick we land in India. Some people may say, But look at the comforts provided by steamships—but I venture to say that after you have travelled by airship and experienced the pleasure of the lack of roll and pitching, not to mention the joys of an 8-course dinner and a selection of excellent wine, all served in a tastefully decorated and well-lighted saloon, with comfortable sleeping bunks to fall into, those people will have no complaints to make. It has only to be experienced to be fully appreciated and so become another convert to travel by airship.

It is generally not realised that airship travel is really not so new and novel as is generally believed. Dr. Eckner in his excellent paper before the R.Ae.S. mentioned that before the war German passenger airships have made over 2,000 flights, carrying 42,000 people without mishap and that after the Armistice the Bodensee, this small passenger ship carried 2,450 people in addition to a large amount of mail matter and freight without any injury to either passengers or crew.

Compare these figures with the total number of first class passengers carried say by the P. & O. to India once a year. It is about 25/30,000 including outward and home passages.

Now let us consider the probable airship routes to be opened in the near future. We will assume the Indian route is established, as the result of the programme I have outlined. It is obvious then that the next step is the extension to Australia. It is yet early days to say whether this extension will be via Calcutta or Colombo to Singapore and so on to either Perth or Port Darwin. Considerable amount of meteorological investigation will have to be carried out before it can be definitely stated which is likely to be the more favourable route. It is even within the realms of possibility that Colombo to Singapore might be the final selection, but as I have previously stated we must await further meteorological data before a final decision can be given on these projected routes. It must also be borne in mind that airships like steamships have an economic range, and when refuelling can be carried out in under 6 hours, it will be readily understood that an intermediate stop will enable a larger commercial load to be carried without seriously interfering with the time of passage.

Other routes which stand out for opening up is the extension from Egypt to South Africa with an intermediate post of call somewhere near East Africa, say Mombasa. This route is important as it will shorten the time of transit of gold from the South African mines to London from 19 to about 7 days; an all-important feature I believe from the money market point of view.

Another route which has received a considerable amount of prominence in recent years is the South American, Rio, Spain, West Africa and Brazil. Generally speaking from a weather point of view this is the most favourable run of all, as full advantage can be taken of favourable winds in both directions. A glance at a sailing ship track chart bears this out. The time taken on this flight from E.B.A. will be about 7 days, allowing for half day stops in Spain, West Africa and Brazil.

The Atlantic flights of R.34 and Z.R.3 bring out the possibilities of this passage. On account of storms and bad weather generally it is of course advantageous to develop on routes with better weather conditions, but as soon as sufficient experience has been gained on the Indian run, attention will no doubt be focussed on the blue riband of the Atlantic.

This run will require ships with a minimum cruising speed of about 70 knots. The route will vary considerably according to the season of the year, sometimes being as far north as 55° and approaching America via Newfoundland, and at others as far south as the Canaries and making New York via Burmuda. On account of the prevailing wind being westerly, the America to Great Britain will on the average be quicker than in the opposite direction. London to New York should take about two and a half days and New York to London two days on an average. From a commercial point of view this run should be very profitable, not only on account of the large numbers of first class passengers available, but also on account of connecting up the two great money markets of the world; gold and commercial documents will no doubt be transported by airship.

As soon as the home trials of the two ships previously referred to are completed, a test flight on the Indian route will be made. This will not only be a test of the ships themselves, but will also prove out the W/T and Met. organisation on the route.

No doubt these two ships being of an experimental nature will require minor modifications before being placed in regular commission, as not only is the size of the ship nearly double the capacity of any previous airship, but in the power units an entirely new type of engine is being installed. In R.101 a semi-Diesel type is being employed and in R.100 an engine running on kerosene hydrogen with opposed cylinders is being adopted.

Let us assume that the minor troubles one expects with all new types of craft are satisfactorily overcome by the end of 1927 and both ships have completed

successful voyages to India. What is the next step in airship development? Assuming before this stage has been reached the Government will have completed negotiations with commercial people to form a company to inaugurate the first Ocean's Airship Transport Co. If the Government turn over both ships to commercial enterprise, it will take another year to 18 months before an additional two ships can be constructed, four ships being necessary before a weekly service can be run efficiently. The next question one has to answer is how will the change over from present-day means of travel be effected? I do not think this is a difficult question to answer. In the first place the public demand for speed has forced the steamship owner to build ships which are not economical and cannot pay except on such selected routes as the North American run; it appears therefore that modern steamship owners will turn over to airship transport for first class passengers and mail traffic, leaving second and third class passengers to be carried on a freighter of 12/14 knots. It is not anticipated that there will be any great increase in the first class fares.

I think you will all agree that it requires no imagination to visualise the effect of airship transport on mails. If the present time of transit is cut down by more than a half I have no doubt the bulk of first class mail will go by air even if there is a surcharge of 2d. per oz.

I have even heard prominent business men say they would readily pay a shilling per letter for such improved facilities, although I do not think this will be necessary. The mail will then also to a large extent take the place of a deferred cable and have the additional advantages of allowing a full explanation to be given rather than a résumé at 2/- a word.

I feel I have gone a little outside the scope of my lecture, which was to discuss the experimental research work essential in any sound airship development scheme, and to point out the means the Air Ministry are employing in the present airship development programme to carry out these experiments. I felt I might also be allowed to discuss some of the reasons why airship development is essential from the commercial point of view.

RÉSUMÉ OF TECHNICAL INFORMATION

Compiled by the Directorate of Technical Development (R.T.P.), Adastral House, Kingsway, London, W.C.2.

AERODYNAMICS

U.S.A.

Model Tests with a Systematic Series of 27 Wing Sections at Full Reynolds Number. N.A.C.A. *Report No. 221.* (1126.)

A systematic series of 27 wing sections, characterised by a small travel of the centre of pressure, have been investigated at 20 atmospheres pressure in the variable density wind tunnel of the National Advisory Committee for Aeronautics.

The results are consistent with each other, and indicate that, for such "stable" sections, a small effective camber, a small effective S-shape and a thickness of 8 to 12 per cent., lead to good aerodynamic properties.

A copy of Report No. 221 by Max M. Munk and Elton W. Miller, describing these experiments, may be obtained upon request from the National Advisory Committee for Aeronautics, Washington, D.C.

AIRCRAFT

Germany

Dietrich Sports and School Biplane, D.P. XI. Luftfahrt. December 20th, 1925. (2126.)

The D.P. XI. is a cantilever biplane with torsion struts. The fuselage is of tubular steel, but many parts are of duralumin, and it is proposed after the flying tests to construct the new type, from the pilot's cockpit to the tail, of duralumin. Part of the fuselage is covered with fabric and part with light metal sheeting.

The top and the bottom wings are each in one piece, and both faces of the wings are covered with plywood as far as the rear spar. Double ailerons are a special feature of this aircraft.

Characteristics.—Engine, 80 h.p. Siemens or 80 h.p. Junkers; span, 26ft. 3in.; length, 20ft.; height, 8ft. 4in.; weight empty, 937 lb.; useful load, 540 lb.; total loaded weight, 1,477 lb.; wing area, 185 sq. ft.; wing loading, 7.94 lb./sq. ft.; power loading, 18.5 lb./h.p.; petrol supply for 3½ hours; oil supply for 5 hours.

Italy

Caproni 50 Night Fighter. L'Aviazione. December 6th, 1925. (3126.)

The Caproni 50 is a biplane with a rigid wing bracing. The wings are semi-thick in profile and the top wing has balanced ailerons. The fuselage is set very low and has both a pilot's and gunner's cockpit. There are two machine guns firing forwards, and one firing downwards can also be fitted.

The engine, which is a 400 h.p. Jupiter, is mounted slightly below the top wing and connected to the fuselage by struts. The airscrew is of wood.

It is stated that the aircraft is easily convertible to an amphibian. The speed, manœuvrability and climbing performances are said to be excellent.

Dewoitine-Ansaldo Fighter Ready for Test. La Gazetta dell'Aviazione. December 17th, 1925. (4126.)

This aircraft is constructed of duralumin with the exception of the wing and control surface covering, which is of fabric. The wing is thick and trapezoidal in shape, and is built in two parts: it is connected to the top of the fuselage by four cabane struts, while four more slanting struts run from the wing to the bottom of the fuselage.

The rudders are unbalanced and a special device enables the angle of incidence of the tail plane to be varied during flight. The undercarriage has Vee struts and the axle is covered with metal fairing.

The engine installed is a 400 h.p. rádial air-cooled Jupiter.

There are two machine guns fitted, firing through the airscrew.

Poland

New Polish Two-Seater Fighter. L'Aero-Sports. December 5th, 1925. (5126.)

This aircraft is a semi-cantilever monoplane. It has thick wings, with a new profile of the double polar type, and a fuselage of duralumin, covered with fibrine. The undercarriage has oleo pneumatic shock-absorbers.

The aeroplane is armed with five machine guns, and it is stated should reach a speed of 150 m.p.h. and have a ceiling of 24,600 feet. The total loaded weight is 3,748 lb.

ACCESSORIES

France

A New Radiator for Aircraft. L'Air. October 1st, 1925. (6126.)

This new radiator is a French patent, by Messrs. Lioré et Olivier. It is intended to reduce head resistance, and to obviate the inconvenience caused by leakages by isolating that part of the radiator where a leakage has occurred. The radiator is made up of a series of elements, divided up by means of bulkheads which can be isolated one from the other either automatically or under control, in the event of a leakage occurring. Each of these elements is formed by two metal sheets, of which at least one is fitted with projections to maintain a constant space between these sheets.

Any part of the surface of an aeroplane which is exposed to the relative wind can be covered by these radiator elements suitably curved to fit the part

The cocks isolating a leakage can be actuated by any suitable form of distance control.

The Pescara Bulletproof Tank. Aviation. December 21st, 1925. (7126.)

This tank, which has been tested by the War Department at McCook Field, is said to provide the means for the partial elimination of fire in aircraft. In addition to being bulletproof and leakproof, the tank is detachable, so that in the event of a forced landing it may be dropped before the aeroplane reaches the ground.

The Pescara tank operates by means of two rotating cylinders, one within the other, which form the walls of the tank. When the cylinders are pierced a mechanism moves the inner cylinder round, approximately four inches, so that the holes in each cylinder are covered by the walls of the other.

During the tests, although the tank was pierced repeatedly by .5 calibre machine gun bullets, none of the contents leaked out.

It is stated that the Pescara tank is about 40 per cent. lighter in weight than any other bulletproof tank.

The Lucien Chevreau Landing Skid. *Aerauto.* November 28th, 1925. (8126.)

This device consists of a caterpillar skid which is fixed to the axle of the undercarriage and prevents the aircraft from turning turtle when it meets an obstruction on the aerodrome. The skid is made up of a framework of steel covered with two duralumin casings, which protect the mechanism from dust and dirt. Inside the casing is a shock-absorbing system mounted on rubber chord shock-absorbers, on which the fixing brackets rest. Excellent elasticity in landing is thus given.

The skid is 4ft. 11in. in length and is said to slide over any hole or hollow in the ground without sinking in. It is well streamlined. It can be mounted on any aeroplane without entailing the slightest modification to the undercarriage.

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CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

DEAR SIR,—With reference to your review of my book, "The Strength of Materials," your reviewer writes:—"The argument on p. 95 is false; *all* the theories there compared give continuous values of the stress."

The sentence to which Miss Hudson takes exception is:—"The strain energy theory gives continuous values to both principal stresses throughout the entire range of positive and negative stresses, *i.e.*, the slope of the curve does not suddenly alter when one of the stresses changes sign." I admit that I have, perhaps regrettably, used the word "continuous" in its colloquial rather than its mathematical sense, but I define the meaning of the word in the last part of the sentence, and the diagrams make quite clear the meaning I intend the word to have.

I think it is important for engineers to grasp the significance of the argument, which is this:—The maximum shearing stress theory demands a kink in the graph where it crosses the axes, whilst the strain-energy theory gives a smooth curve without such kinks. In nature one expects smooth curves and not kinks. No one, in laboratory tests, has detected any such kink. The shearing stress theory demands that slip should occur on different planes in the two cases; experiment shows that in a single crystal the planes will often be the same in the two cases, although they may be different. From this one concludes that, in the aggregate, there will be no such difference of plane as is accepted by the shearing stress theory.—Yours faithfully,

JOHN CASE.

R.N. Engineering College,
March 18th, 1926.